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The water balance in Graminha Basin

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ABSTRACT

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Today, only 7 % of the Atlantic Rainforest, that once covered Brazil, remains scattered across the southern parts of the country. As the forest is rapidly disappearing, the government of Brazil has emerging interest of preservation. Thus more and more areas are turned into national parks and reserves. At the outskirts of one of these reserves, the Iracambi research station is situated. The center makes an effort to carry out applied research to find methods of preserving and learning about the forest. It is within that context the project described in this report has been performed. The project aimed to establish a water balance over Graminha Basin, the main river in the Iracambi research area. By doing this the understanding of the fluctuations of the amount of water in the ecosystem could increase. An important part of the objective was also to assess which methods can be used practically at Iracambi.

The project was carried out during the rainy season from February 13th to April 12, 2012. During this time the water flow was measured at five stations along the river, using a current meter and instant slug-injection. Between six and fifteen flow measurements were made at each station. Slug- injection was generally the most suitable gauging method to use in the area. Precipitation was measured at two points. Evaporation was measured using an evaporation pan, and also calculated using the Penman-Monteith equation. Even though, the parameterization of the Penman-Monteith needs to be improved it was deemed to be the more suitable method for the area.

The results give a rough estimate of the water balance during the period. It was concluded that the storage decreased during the project period. Based on the flow measurements and observations it was concluded that the areas covered by forest were less affected by the floods that occurred during heavy rainfalls than the areas covered by grass. Further on, the result of this report indicates that the Iracambi research station can continue to carry out assessments for changes in water flow, rainfall and evaporation with the simple equipment used in this project. However, more expensive and advanced equipment would be beneficial to establish a more accurate water balance.

Keyword: Water Balance, Atlantic Rainforest, Iracambi

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REFERAT

Vattenbalansen i Graminha Basin

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Idag återstår endast 7% av den atlantiska regnskogen som en gång täckte Brasilien södra kust. Regnskogen försvinner snabbt vilket har lett till att Brasiliens regering de senaste åren visat ett ökat intresse att bevara regnskogen. Fler och fler områden har förvandlats till nationalparker och reservat. I utkanten till ett av dessa reservat ligger forskningsstationen Iracambi. Iracambi bedriver forskning i och runt området för att hitta metoder för att bevara regnskogen och öka kunskapen om området. Detta projekt är ett litet bidrag till detta arbete. Det övergripande syftet med projektet var att upprätta en vattenbalans över floden Graminhas avrinningsområde. Detta är huvudfloden i området och genom upprätta en vattenbalans kan förståelsen för förändringarna av vattentillgången i ekosystemet öka. Ett viktigt mål med projektet var också att finna verktyg som forskningsstationen Iracambi kan använda för kontinuerliga mätningar av de parametrar som ingår i vattenbalansen.

Projektets genomfördes under regnperioden mellan den 13 februari och den 12 april, 2012. Flödesmätningarna utfördes vid fem mätstationer längs floden Graminha. Två typer av utrustning användes: flygel och konduktivitetsmätare. Rekommendationen för Iracambi var att fortsätta mätningarna med framförallt konduktivitetsmätaren. Uppskattningarna av avdunstningen genomfördes på två sätt: dels genom upprättandet av en evaporationspanna, dels genom beräkningar. Beräkningarna genomfördes med Penman-Monteith ekvationen och det kunde konstateras att även om de ingående parametrarna innehåller en del osäkerheter, så var detta den mest passande metoden för att beräkna avdunstningen. Nederbörd mättes på två platser med hjälp av enkla regnmätare konstruerade av pet-flaskor.

Slutligen upprättades en vattenbalans för området. Utifrån denna kunde det konstateras att vattenmagasinet för hela orådet minskade under mätperioden. Utifrån flödesmätningar samt observationer kunde slutsatsen dras att skogsområdena drabbades mindre än de gräsbevuxna områdena av de kraftiga översvämningarna som uppstod under intensiva regn. Vidare visar resultaten att forskningsstationen Iracambi kan få en bra uppskattning av flödesförändringar, nederbörd och avdunstning med hjälp av den enkla utrustning som användes i detta projekt.

Nyckelord: Vattenbalans, atlantiska regnskogen, Iracambi

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PREFACE

This project was carried out as an Independent Project in Environmental and Water Engineering at Uppsala University. The project constitutes 15 university credits, and was carried out at the research station Iracambi, which is located in the Atlantic Rainforest in the province Minas Gerais, Brazil. Supervisor at Iracambi was Mr. Robin Le Breton. Supervisor from Uppsala University were Professor Lars-Christer Lundin and Professor Jan Seibert both at the Department of Earth Science at Geocentrum in Uppsala.

First we want to give a lot of thanks to Senior Lecturer Ronny Alexandersson, Senior Lecturer Roger Herbert and Professor Allan Rodhe, for helping us with equipment and the overall work, all the small necessary things that takes a lot of time. We also want to emphasise our appreciation of all the time you have invested in the completion of our report.

Secondly, we want to give thanks to Mr. Robin Le Breton for supporting and helping us during the project. Special thanks to the people in the village that have been very helpful with all type of assistance, from cutting bamboo to giving us a ride to the hospital or helping us catch a bus.

We also want to give a sincere thanks to Professor Seibert, who has helped us immensely with the technical aspects of the project as well as giving us thorough feedback on our written report. Finally, we are very thankful for the support and supervision by the late Professor Lundin, who played a great part of getting the scholarship needed for this project. His encouragement helped us to achieve a memory for a lifetime. Thanks.

POPULÄRVETENSKAPLIG SAMMANFATTNING

Beatrice Aulin och Linnea Henriksson

Brasiliens atlantiska regnskog är i riskzonen att försvinna. Omfattande insatser görs för att förhindra denna utveckling genom att bl.a. införa nationalparker. En av dessa är Sierra do Brigadero och i gränstrakterna till denna ligger forskningsstationen Iracambi. Iracambi söker efter lösningar för att kunna omvandla sitt område till en buffertzon för nationalparken. Under detta projekt har nya verktyg och metoder tagits fram för att Iracambi lättare skall kunna övervaka vattnets flöde in och ut ur systemet. Systemet karaktäriseras av floden Graminha vars avrinningsområde definieras av hög terräng, med dalar och berg. För att möjligöra kontinuerlig övervakning av systemets vattenfluktuationer, genomfördes detta projekt med syftet att sätta upp en vattenbalans för området, samt hitta enkla metoder för fortsatta mätningar av de parametrar som ingår i vattenbalansen. Mätningar och beräkningar av de ingående parametrarna; avdunstning, nederbörd och vattenflöde genomfördes dagligen under mätperioden. Slutligen beräknades storleken på förändringen av vattenförrådet i marken. Resultatet gav en uppfattning om hur vattenförrådet ändrades under projektperioden.

Avdunstning mättes på två sätt, dels med en hemmagjord evaporationspanna och dels genom beräkningar med Penman-Monteith ekvationen. Vattennivån i evaporationspannan mättes vid samma tidpunkt en gång per dygn och utifrån dessa värden beräknades den evaporerade vattenmängden. Eftersom regn inte får inträffa under mätdygnet, blev antalet mätningar begränsat eftersom det ofta regnade på natten. Vidare lämnar lokalbefolkningen sällan kärl med vatten stående eftersom det kan öka förekomsten av myggor som är bärare av Dengue feber. Därför fastställdes att detta verktyg var mindre lämpat för regionen. Den använda ekvationen var beroende av en mängd generaliserade konstanter samt mätdata på daggpunkt och temperatur, vilken görs av en mindre väderlogger, och uppskattningar av observerad molnighet under dygnets soltimmar. Parametrarna i denna ekvation innehåller en del osäkerheter, men trots detta anses det vara den mest lämpade metoden eftersom kraven på mätdata är begränsad samt att loggern möjliggör lagring av data som kan hanteras vid senare tidpunkt.

Nederbörd mättes med hjälp av enklare nederbördsmätare konstruerad av pet-flaskor, vars innehåll samlades upp, mättes och vägdes manuellt efter varje regn. Under genomförandet av projektet observerades det att det förekom lokala regn på grund av den höga terrängen. Vid ett flertal tillfällen iakttogs regn över områden där nederbördsmätningar inte genomfördes. På grund av detta drogs slutsatsen att forskningsstationen Iracambi med denna metod endast kan få en grov uppskattning av nederbörden i området. Vidare observerades det vid ett flertal tillfällen översvämningar och kraftigt flöde utan några större uppmätta nederbördsmängder. Detta visade sig bero på att regntunga moln kolliderade med bergstoppar vilket orsakade kraftig nederbörd med en direktpåverkan på floden. Den höga terrängen medför därför att avancerade nederbördsmätare måste användas för att ge korrekta värden, eftersom det inte är fysiskt möjligt att manuellt samla in data från det antal regnmätare som behövs för att täcka området. För en uppskattning räcker det dock med de enklare modellerna som användes.

Vattenflödet mättes vid fem mätstationer längs floden med hjälp av två olika mätinstrument, flygel och konduktivitetsmätare. Flygel är ett propellerformat instrument som mäter vattnets hastighet vid en viss punkt i floden. Flygel användes vid två mätstationer, där mätningar utfördes vid olika djup och vid olika avstånd från flodbanken. Detta möjliggjorde att den uppmätta hastigheten kunde sättas i relation till vattendragets tvärsnittsarea, och därigenom erhölls vattenflödet i floden. Konduktivitetsmätare är ett instrument som mäter en vätskas ledningsförmåga. Då ledningsförmågan egentligen är ett mått på antalet fria negativa joner så kan man lösa upp koksalt, NaCl, i vatten och därigenom få ett utslag på konduktivitetsmätaren. För vattenflödesberäkningarna i Graminha användes detta samband, genom att en bestämd mängd salt blandades i en hink med en bestämd mängd vatten från floden. Hinken tömdes på en punkt och nedströms mättes konduktiviteten. Vattendragets konduktivitet ökade således när saltvågen passerade, för att därefter återgå till sin ursprungsnivå. Då saltkoncentrationen i hinken var känd kunde slutligen vattenflödet i floden beräknas. Efter genomförda mätningar konstaterades det att det instrument som lämpade sig bäst för flödesmätningar på de flesta platserna i området var konduktivitetsmätare. Detta berodde på att vattendragen ofta hade en otydlig korrelation mellan vattennivå och tvärsnittsarean, samt att den steniga bottenkompositionen skapade stor turbulens vilket hade en försämrande effekt på flygelmätningarna.

Den slutgiltiga sammanställningen av vattenbalansen visade på att vattenförrådet i marken minskade trots att detta var tiden för regnsäsong. Detta kan antagligen förklaras med att perioden var ovanligt varm och torr, och att de kraftiga regnen inträffade först i slutet av perioden för projektets genomförande. Utifrån flödesmätningar samt observationer kunde slutsatsen dras att skogsområdena drabbades mindre av de kraftiga översvämningarna som uppstod under intensiva regn. Detta var ett förväntat resultat eftersom växter och trädrötter tenderar att hålla vatten bättre än områden med bara gräs, samtidigt var det ett viktigt resultat med tanke på att området ständigt hotas av skogskövling.

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1 INTRODUCTION

1.1 BACKGROUND

When Europeans arrived to the land that would become Brazil it was covered by Atlantic rainforest. This forest was and is the home to a vast number of species of animals and plants and it is one of the forests with the greatest biodiversity in the world (Sos Mata Atlântica, 2013). Unfortunately human impact has had a devastating effect on the forest and the ongoing human activity is continuing the marginalization of the forest distribution. Further on, unsustainable agricultural practices result in erosion, loss of soil fertility, over-grazing, and strain on water resources, leading to a cycle contributing to rural poverty. Many of the species that reside in the Atlantic rainforest are endemic and much of its immense variety of flora, fauna and animals are endangered by the habitat loss (World Land Trust, 2013). Today only 7 % of the original forest remains. As a part of an effort to protect and preserve the remaining areas covered by Atlantic rainforests, the authorities in Brazil have converted some of these zones into national parks and reserves (Sos Mata Atlântica, 2013). One of these parks is called Serra do Brigadero and next to it a small research station, Iracambi Atlantic Rainforest Research and Conservation Center, is located. Except for carrying out applied research into the causes of deforestation and land degradation, the owners and staff at Iracambi are working to transform its surrounding area to become a buffer zone to the park. It is within that scope that Iracambi research station has an interest in understanding the dynamics of the hydrology in its adjacent river Graminha.

The Graminha basin is located within the municipality of Rosáiro da Limeira in the southeastern parts in the state Minas Gerais. Regarding population, size and economy, Minas Gerais is one of the largest states in Brazil (Governo de Minas Gerais, 2013). The area is characterized by mountains, hills and grasslands with patches of Atlantic rainforest. Graminha basin is approximately 35 square kilometers in size, and is primarily inhabited by small farmers and landowners, who rely on the cultivation of land as the primary source of income. Aside from using cleared land for cattle grazing, farmers grow coffee, corn, eucalyptus, sugar cane, and beans. The basin is one of the upstream catchment areas for the Rio Preto, one of two main rivers that supply water to the residents of Muriaé, a city of 100 000 inhabitants (Guia Muriaé, 2013).

Iracambi Atlantic Rainforest Research and Conservation Center are working for the aim that people and forests can grow and prosper together. To obtain this objective, Iracambi is working with programs of research, education and practical actions (Iracambi, 2013). Iracambi research station is creating protected areas, growing and planting forest trees, monitoring the health of the forest, its water, soils and fauna. The research station is also working with community-based tourism and payment for environmental services (PES). PES primarily offer economic incentives to encourage more efficient and sustainable use of ecosystem services (Forest Trends, The Katoomba Group, and UNEP, 2008). PES can enable low-income people to earn money by restoring and conserving ecosystems. In the region where Iracambi research station is situated farmers are cutting down the forest for farming activities. The idea with PES is that the possible additional income source will influence the farmer´s attitudes towards conserving forests. If the forest could provide additional revenue, this could be the deciding factor if the farmer will cut down or preserve the forest. Within this scheme of Payment for environmental services it is of interest to examine the potential of a water conservation scheme that rewards smallholders for their role in conserving and generating water resources. One important component concerning water conservation is the correlation between land use and water supply. However, this demands an understanding of the water balance that Iracambi research station, at the moment, does not possess. To establish a relation between land use and water supply for the specific area of interest, an examination of the water balance needs to take place.

1.2 THE PURPOSE

The aim of this project is to survey the features of the water balance in Graminha Basin, as well as identifying a correlation between land use and water supply.

Since Iracambi works with research and preservation, as well as information and education of the local community, the project also has a second objective. The second objective of the project is to create programs and methods that facilitate Iracambi's measurement of water flow, evaporation and precipitation. Thus this project will enable continuous monitoring of the behaviour of the water flow in the ecosystem. The hope is that Iracambi manages to spread knowledge about the water balance as well as the importance of it to the local community.

2 METHOD AND PRACTICE

The water balance in a defined ecosystem can be described as the following equation (Hendriks, 2010, p. 10):

$$Q = P - \Delta S - E \qquad (1)$$

Q is the water flow that enters and exits the borders of the ecosystem, P is precipitation and E is the evapotranspiration, which is the sum of evaporation and plant transpiration. ΔS is the change in storage (in soil or the bedrock). To enable assessment of the water balance, three parameters were measured on site; river flow, precipitation and evaporation. Several methods and equipment were used to carry out the measurements for each parameter. Afterwards the change in storage was calculated by rewriting equation (1). In the following sections, both methods and implementations are presented.

2.1 METHOD FOR MEASURING WATER FLOW

Two types of methods were used to carry out the measurements for water flow. The first one, the velocity-area method was accomplished with a current meter. The other method, salt dilution was carried out by using a conductivity meter. The characteristics of the stream determined which technique to use. By installing a staff-gauge the correlation between the height of the water table and the discharge of the river could be obtained.

2.1.1 The velocity-area method

A well-known instrument for determining the water velocity at different locations and depths in a stream is the current meter. The current meter used for this project was connected to a Vernier logger. The current meter was set to measure the velocity of the stream every second during 30 seconds and then calculate the mean velocity of the stream. Using this current meter, the discharges of the river was determined using the velocity-area method. The technique means to sum the discharges through segments of the cross-sectional flow area. Figure 1, shows an example of how the areal cross section of the river was divided into smaller sections. Every section was 0.6 or 1 meter wide, adapted to the specific characteristics of the river (Hendriks, 2010, p. 229-230).

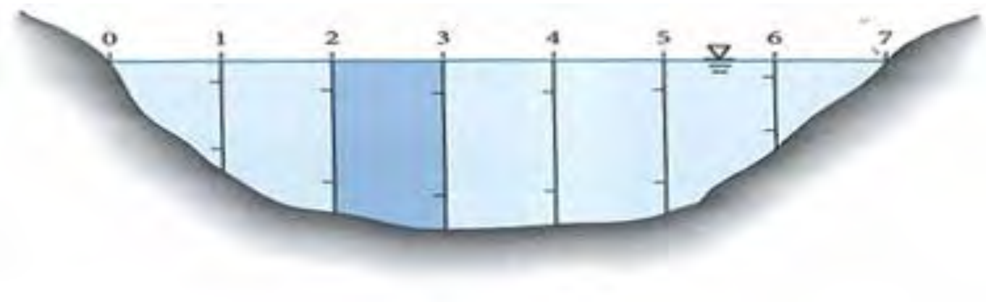


Figure 1: An upstream view of the cross-sectional flow area perpendicular to the water flow, here divided into seven sections *(Source: Hendriks, 2010, p.230).*

By standing in the water, the velocity was measured at every section, at different depths. To minimize the error, the interval of the measurement depths was chosen to only 10 cm. A program was written in MATLAB to calculate the water flows, see Appendix C, section: *Flow measurement using current meter*. Figure 2 shows an example of how the different water velocities (m/s) vary with the water depth. By integrating the areas shown in the figure the discharge per unit width (m^2/s) was obtained at every section. Each square in the figure represent the measurement made every 0.6 meters of the river, at point 1, 2, 3, 4, 5, 6 in Figure 1.

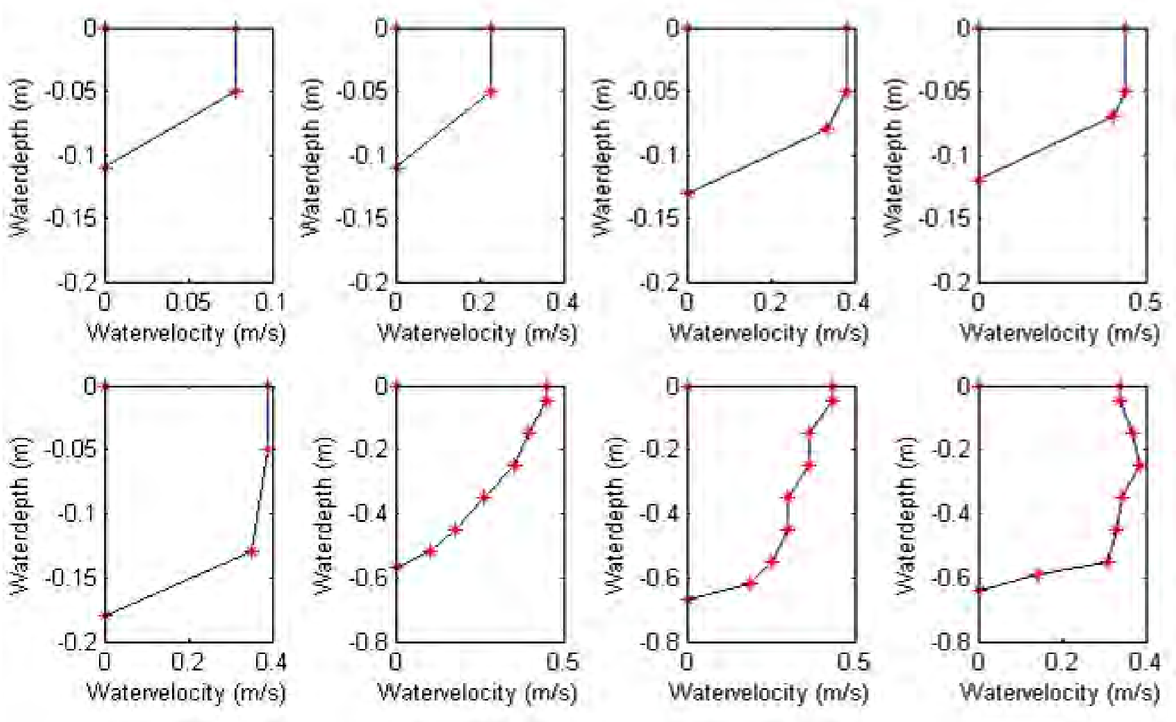


Figure 2 The velocity of the water (x-axis) at different depths (y-axis). The six squares represent different locations along the cross-sectional flow area.

In the same MATLAB program a graph was created that shows the calculated discharge per unit width (m^2/s) and the distance from left riverbank, se Figure 3. By integrating this graph the discharge Q (m^3/s), of the river was obtained. Since the discharge was small the unit was changed to l/s.

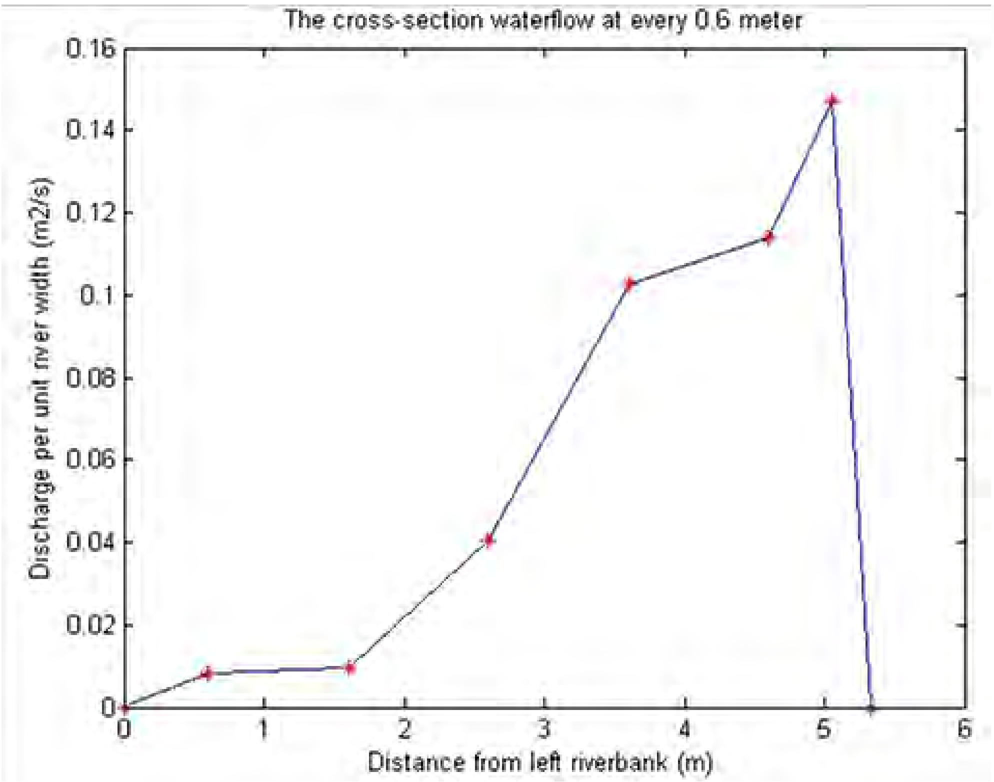


Figure 3 The calculated discharge of water at each section (y-axis) and the distance from left riverbank (x-axis).

To be able to use the velocity-area method, a homogeneous bottom composition as well as a controlled cross area as the water level rises is required. Finally, absence of large objects at the bottom like rocks that prevent or change the flow is required. Two measurement points in the Graminha River fulfill these criteria, W5a and W2

2.1.2 Slug injection

In mountain streams a current meter can be difficult to use due to the turbulence of the water flow, high velocities, rocks and shallow sections. A technique that suits the estimation of the discharge in turbulent mountain streams is the salt dilution gauging. For streams up to 10 000 l/s a reliable measurement method is slug injection with salt, where a bucket of salt dilution is emptied instantaneously into the stream (Hendriks, 2010). The principle of instant slug injection can briefly be described as a measurement of the change of conductivity at a measurement point, downstream the injection point. The slug causes a saltwater wave to pass the downstream measurement point. Conductivity ($\mu S\ cm^{-1}$) is a measure of the ability of water to conduct an electrical charge, hence a measure of the concentration of ions in the water (Hendriks, 2010, p 230-236). The conductivity was measured for every second by using the Vernier logger. The collected data of conductivity resulted in a graph showing the passing of the saltwater wave, an example at different measuring days and water depths is shown in Figure 4. The horizontal axis represents time and the vertical axis shows the concentration of salt (mg/l), which has been calculated from the measured conductivity. In MATLAB the area within the blue lines was calculated (mg·s/l) by using equation 2, where c is the salt concentration in the river (mg/l) and t is the time (s).

$$\int_0^\infty c(t)dt \tag{2}$$

The water flow of the river at the monitoring point could later be calculated by using equation 3.

$$Q = \frac{C_0 V}{\int_0^\infty c(t)dt} \tag{3}$$

Q is the water flow (l/s), C_0 is the salt concentration in the bucket (mg/l) and V is the volume water in the bucket (l). The relation between conductivity and concentration of salt was found through a calibration of the conductivity meter, see appendix A.

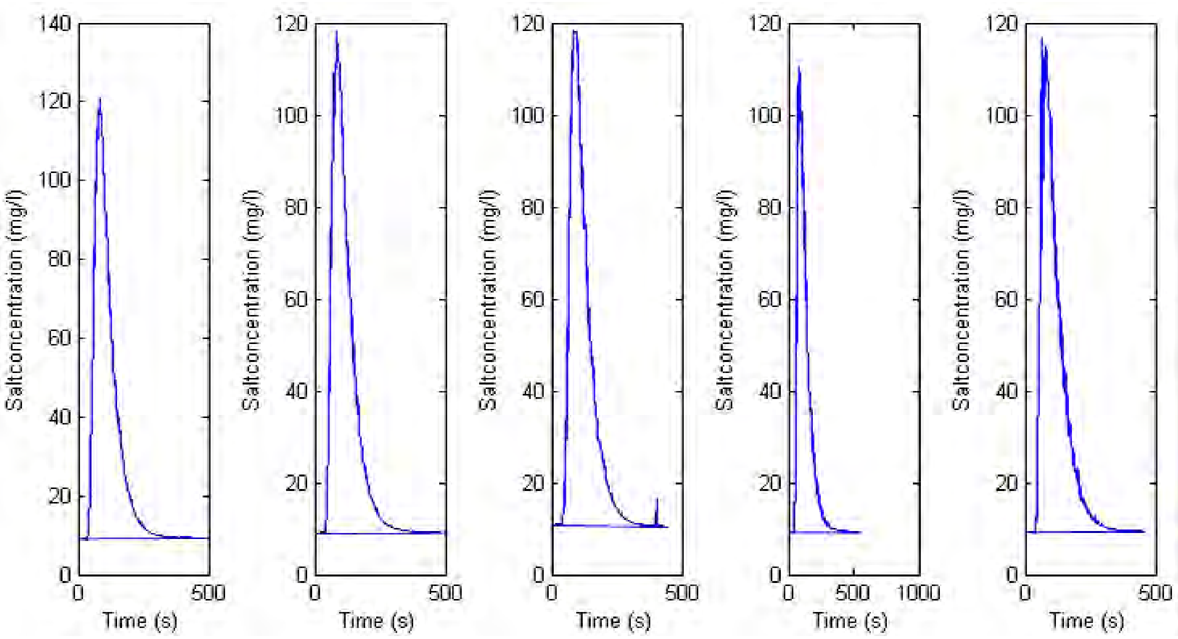


Figure 4 The passing saltwater wave at different measuring days.

At the research center, a regular scale was used to weight the salt. Regular cooking salt, NaCl, was used for the slug injection. The maximum weight of the scale was 300 grams, with three significant numbers. The weighted salt was transported to the monitoring point and mixed with river water in a bucket to a pre-determined concentration. The bucket was emptied at an accessible point upstream with enough distance and turbulence to let the bucket blend mix with the water in the river. The data was collected downstream with the Vernier equipment and afterwards calculations were performed in MATLAB, see Appendix C, section: *Flow measurement using instant slug injection*. The concentration of the bucket blend was normally 700 grams of salt in 7 litres of water, but it was adapted when necessary to the amount of flow in the river. During low flow, the concentration in the bucket was low to prevent the measured conductivity to spike and damage the equipment. During high flows the concentration of salt in the bucket was high in order to enable good recording of the conductivity change.

Slug injection was used at each measurement station along the river. At W8, W7 and W5 this was the only method used. When the river flow at W5a and W2 was extremely high and the turbulence too forceful to be in the water this equipment could be used as a compliment to the current meter.

2.1.3 Staff-gauge

On all measurement stations a staff-gauge made of bamboo was installed. The resulting correlation between the height of the water table and the discharge of the river made it possible to determine the water flow just by measuring the water depth. This meant that the time to monitor the measurement station could be immensely reduced. It also made it possible to catch the flow peaks during heavy rainfall. By standing next to the staff-gauge and register the water depth every minute during and after a rain, the water flow for the same period could be calculated later. At the measurement stations W5 and W5a, the water depth was manually registered once a day when there was no rain. Since these were the stations closest to the research station, they were also the ones observed during rainfalls. The water depth was monitored every minute to every tenth minute, depending on the intensity of change.

At the measurement station W2 a pressure gauge of model CS450 from Campbell Scientific Inc was installed (Campbell Scientific 2009-2013). The pressure gauge measures the pressure in kPa relative to the atmospheric pressure, with the measuring interval 0-1000 kPa. The measuring principle is based on piezoelectricity. The lower part of the pressure gauge consists of piezoelectric crystals that are symmetrically distributed over a surface. When these crystals are subjected to pressure the symmetry of the crystals are destroyed which gives rise to a electrical voltage on the crystal surface (National Encyclopedia 2013). This voltage is proportional to the pressure. The measured pressure can later be converted to water depth through a simple calibration. The calibration was performed at Iracambi research station, as presented in Appendix B. The pressure gauge was placed in an empty measuring cylinder and water was added step-by-step so that the actual water depth could be measured manually, and a correlation between water depth and the measured pressure was created. The pressure gauge was connected to a logger of model CR1000 (Campbell Scientific), that recorded the water depth every minute and then saved the mean value every 5 minutes. Hence continuous measurements of the height of the water table could be made at this point in the river.

2.1.4 The stage-discharge relation

The relation between the height of the water table and the discharge of the river can be described by the power equation, (Hendriks, 2010, p. 241):

$$Q = a(h - h_0)^{\,b} \tag{4}$$

where Q is the discharge (l/s), h the water level (cm), h_0 is the water level along the staff gauge at which the discharge equals zero, a and b are constants. By rewriting the power equation (4) in logarithmic form the values of a and b can be found.

$$log\,Q = log\,a + blog(h - h_0) \tag{5}$$

As shown in Figure 5 the (log (h-h_0), log Q) data can be plotted as a straight line (y = slope·x + intercept) in a graph with log Q on the vertical y-axis and log (h-h_0) on the horizontal x axis.

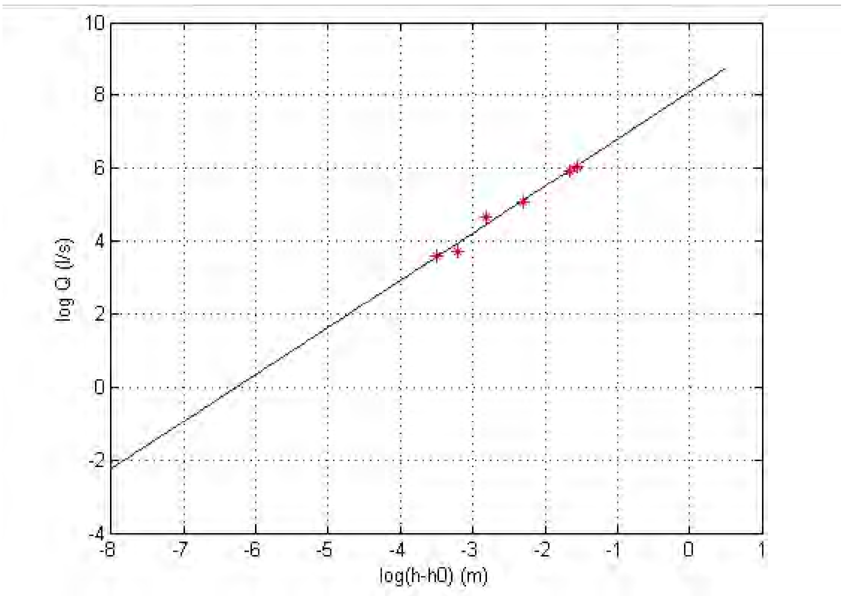


Figure 5 The power-equation in logarithmic form. The y-axis represents the natural logarithmic value (ln) of the discharge Q, and the x-axis is the logarithmic value (ln) of the difference between the water table and the water table along the staff gauge at which the discharge equals zero.

A program was written in MATLAB that rewrites the equation on natural logarithmic form (ln) and plots this and the power equation for different h_0. The different graphs were then carefully studied and the one that best matched the points was chosen. From the MATLAB program the values of a, b and h_0 was obtained.

2.2 FLOW MEASUREMENT STATIONS

2.2.1 Selection of measurement stations

The first days of the project was dedicated to find and select stations in the river where flow measurements could be made. Iracambi research station already had 10 points where flow measurements were conducted approximately once a month. In first place these measurement points were investigated as plausible stations for this project. Figure 6 shows the existing 10 points and also one extra, W5a, which was a station added during this project. Also the research station, labelled as “El Centro”, can be seen in the figure. From now on, the research station, which was the starting position for all practical work carried out at Iracambi, will be referred to as El Centro.

at t e

on t e

Elevation: 750 – 1100 m

Figure 6 Graminha Basin with the 10 existing measurement points, W1-W10. Also the new station added in this project W5a, is shown *(Source: Iracambi Research Station)*.

During the investigations of plausible stations for flow measurements, several observations were made of the river's general characteristics. Firstly, the tributaries upstream, which originate from the sides of the mountains in the area, are very small with a width of 0.5 to 1 meter. These streams are too small and often too far away from El Centro to be of interest. Downstream the river gets wider to a width of 6-8 meters. Secondly, the riverbed consists of a combination of rock, gravel and fine sand. The riverbed composition is also heterogenic throughout the river. Thirdly, the base depth in the river, that is the depth when it has not been raining in some days, is around 25-40 cm upstream as well as further down in the river. Transportation by foot was challenging and time consuming, e.g. the walk to the measurement point W8 took about one hour. Figure 7 shows the topography of the area.

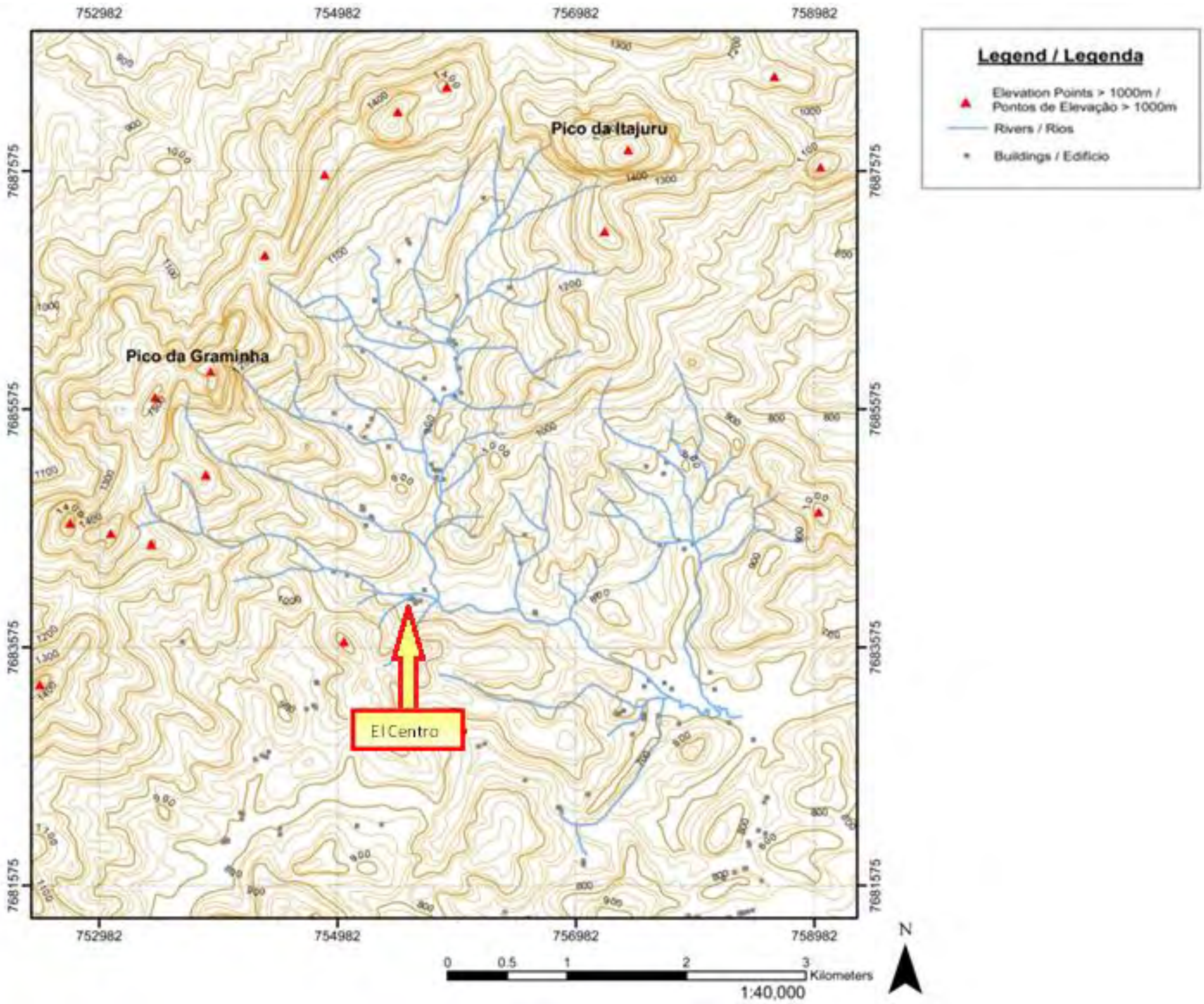


Figure 7 The topography of Graminha Basin Source; *Iracambi Research Centre*.

It was decided to locate the measurement stations along the main river, with one exception, W5. The measurement stations W8, W7 and W5 further up the river were considered to be suitable for slug injection with salt.

All the stations were equipped with a staff-gauge in an effort to create the correlations between water flow and water level. Two measurement stations were found to agree with the criteria for using the velocity-area method, W5a and W2. The pressure gauge was located furthest downstream at the measurement station called W2. This measurement site was followed by W5a. As can be seen in Figure 6, W5 is the only measurement station that is not located in the main river. The reason of choosing this place was to observe the effect of the forest as well as its convenient location close to El Centro.

The physical point of origin for all the collected data was at El Centro, hence all the measurement stations were chosen within the reach of this point. Below, each of the measurement stations are presented starting at the point furthest upstream.

2.2.2 W8

This point could experience large flows during heavy rains but dramatically less than other areas. This was probably due to the relatively low base flow and other physical aspects of the river and the surrounding environment. Figure 8 shows a downstream view of the measurement station and the staff gauge.

Figure 8 Downstream view of the measurement station W8 and the staff gauge.

2.2.3 W7

This point was initially considered to be a good measurement point using slug injection and a staff gauge. The dramatic change of flow flushed away the staff gauge and the difficulties regarding access made it less good during the rains. However, it is a very good place to preform slug injection. Figure 9 shows a dowmstream view of the measurement station W7 where an ongoing flow measurement with slug injection is made.

Figure 9 The view dowmstream at the measurement station W7 where an ongoing flow measurement with slug injection is made.

2.2.4 W5

This point was close to El Centro and enabled the measurement of a flow solely characterized by forest. This was also the only point where a tributary was monitored. Figure 10 shows the measurement station from the side and the staff gauge made of bamboo.

Figure 10 The measurement station W5 from the side and the view upstream.

2.2.5 W5a

Likewise as the measurement stationW2, this place was selected due to its relatively favorable qualities as compared to other parts of the river. Furthermore, this would be a easily accessible place due to its location adjacent to El Centro. The bamboo construction was fixated in the ground to avoid that it got flushed away during strong water flows. Flow measurements were carried out by using a flow meter and the width of each areal cross section of the river was 1 meter. During rain the staff gauge was used to measure the dramatic change in water level to create a hydrograph. Flow measurements were also made by using slug injection. Figure 11 shows an uppstream view of the measurement station after a rain when the water level is high. The staff gauge is placed at the left side of the river (right side in Figure 11).

Figure 11 An uppstream view of the measurement station after a rain when the water level is high.

2.2.6 W2

Due to its relatively straight shape with no preventing obstacles and a homogenous river bed as well as its location further downstream, it was decided that this measurement station was to be monitored by the pressure gauge.

As can be seen in Figure 12, a construction was created to fixate the vertical bamboo stick where the pressure gauge was fastened with duct tape. To prevent the water flow from moving the large horizontal bamboo downstream, blocks of wood was buried deep into the ground as can be seen down to the left in the figure. Since flooding could lift the construction, a plank was placed horizontally over the two blocks of wood.

Figure 12 An upstream view of the measurement station W2 when the water level is low. At the left side the "nest" with the logger can be seen.

Further on, a small "nest" above ground was built to prevent the logger from being soaked if the area should be flooded, see Figure 13. Since the measurement station was situated in grasslands that host a lot of cattle, the construction was also designed to be "cow proof" according advisement from Mr. Le Breton. Apparently the cows have a tendency to rub against any obstacle sticking up from the ground.

Figure 13 A view from the side of measurement station W2 and the pressure gauge.

The final construction was stable against both cows and most of the rains. However during some of the heavier rains, the force and the turbulence of the water could partially rip the construction apart. Thankfully the nest with the logger remained unharmed during such events and the data before and after the incident was saved. These floods also caused erosion of the river walls that changed the cross section area and the river bed. Since this station was initially designed to be measured manually with the current meter, the changed cross section area resulted in the need of adapting the interpretation of collected data.

Further on, manual flow measurement during the initial part of the heavier rains could not be made since the flooding of the river efficiently prevented passage to the station. During such events the water flow was also too heavy to use the current meter, and the measurements were carried out by using slug injection. The slug injection took place further upstream and for each level of flow, adaptations were made regarding the concentration of the bucket so that a change in conductivity could be measurable despite the heavy flow. The slug injection method was therefore used at several occasions to obtain a stage-discharge relationship.

2.3 PRECIPITATION MEASUREMENTS

Low-budget rain gauges, constructed from plastic bottles, were used for measuring precipitation. The top was cut from the bottle at about two-thirds of the height of the bottle and the top was turned around, as shown in Figure 14. The top of the bottle catches the rainfall and the lower part stores the rain. The idea with the turned around top is to minimize the evaporation (Hendriks, 2010). Two low-budget rain gauges were constructed and the area of each bottle was about 80 cm^2. To avoid effects from surrounding vegetation, the bottles were placed openly with an angle less than 45° between the bottle and the highest nearest vegetation.

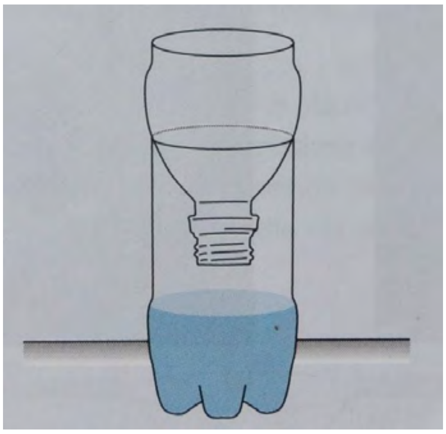


Figure 14 Low-budget rain gauge, constructed from a plastic bottle. *(Source: Hendriks, 2010, p.27).*

One was placed at El Centro, to the left in Figure 15. The second one was placed about 2.5 kilometers upstream, close to measurement station W7, to the right in Figure 15. The idea of two measurement points is to get data of the precipitation with some regard to topography as well as increasing the reliability. The water in the rain gauge number one was collected after every rainfall. Due to the considerably time it took to walk back an fourth to W7, approximately 1 hour, the water in the rain gauge number two was collected every time measurement station W7 was visited.

Figure 15 Low-budget rain gauge located close to El Centro to the left and close to W7 at the right

2.4 METHOD FOR EVAPOTRANSPIRATION

Evapotranspiration was calculated by using the Penman-Monteith equation. Also, a evaporation pan was constructed to measure the evaporation.

2.4.1 Estimation of evapotranspiration using the Penman-Monteith equation

Penman-Monteith equation calculates actual evapotranspiration. Iracambi has a small weather station by Davis Machines LTD, located at El Centro as shown in Figure 16.

Figure 16 The weather station at El Centro at 750 – 1100 m

The station measures high and lows for air pressure (hPa), rain (mm), wind (mph), humidity (%), Temperature C) and dew point for intervals of 24 hours. These measurements enabled estimation of evapotranspiration (mm/day) by using the Penman-Monteith equation, equation (6),(Hendriks, 2010, p. 34-47):

$$E = 0.408 \cdot \frac{\Delta \cdot R_n + \frac{105.028(e_s - e_a)}{r_a}}{\Delta + 0.067\left(1 + \frac{r_s}{r_a}\right)} \qquad (6)$$

where e_a and e_s are actual- and saturated water pressure (kPa), r_a and r_s are aerodynamic as well as surface resistance(s/m). Δ is the gradient of the saturation pressure curve (kPa/ºC) and can be calculated by equation (7):

$$\Delta = \frac{0.4098 e_s}{(237.3 + T)^2} \qquad (7)$$

where T is temperature measured on site C). In equation (6) R_n is the net-radiation at the earth surface (MJ/(m^2 day)) and can be calculated by using equation (8):

$$R_n = S_n + L_n \qquad (8)$$

S_n is the net incoming short wave radiation at the earth’s s rf ace (MJ/(m^2 day)) and Ln is the net incoming long wave ra at on at the earth’s s rf ace MJ/ m^2 day)) (Hendriks, 2010, p. 34-47).

The equations have been calculated with values for the constants and variables according to table 1.

Table 1 The values of the constants and variables used for calculation evapotranspiration

Parameters/ variabels	Description and units	Further information
T [ºC]	Temperature measured on site	Measured by Davis equipment, average based on maximum and minimum values for each day
S_0 [MJ/(m² day)]	Incoming shortwave radiation on top of atmosphere	Estimated for each day based on latitude of Iracambi and day of year, Figure B2.12. 2. (Hendriks(2010), p. 37)
n/N	Cloudiness fraction	Estimated for each day on site. based on the following values; Over cast= 0.05 Semi-overcast 1(Partially cloudy) =0.25 Semi-overcast2 (Partially sunny)= 0.5 Sunny= 1.0
RH	Relative humidity	Based on measurements of dew point and temperature by the Davis equipement
r_a [s/m]	Aerodynamic resistance	1. Rain forest = 8, [5-10] 2. Grass land = 60, [50-70] 3. Open water = 120 [110-125] (Hendriks(2010), p. 41, table 2.1)
r_s [s/m]	Surface resistance	1. Rain forest = 100, [80-150] 2. Grass land = 60, [40-70] 3. Open water = 0 (Hendriks(2010), p. 41, table 2.1)
Alb	Albedo	1. Rain forest = 0.12 2. Grass land = 0.26 3. Open water = 0.12
e_s [kPa]	Saturation vapour pressure	Calculated by using temperature for each day
e_a [kPa]	Actual vapour pressure	Calculated by using calculated values of RH and e_s
S_n [MJ/(m² day)]	the ncom n short wave ra at on at the earth's surface	Calculated by using calculated values of S_0, n/M and Alb
L_n [MJ/(m² day)]	Ln is the incoming long wave radiation at the earth's s rface	Calculated by using calculated values of T, e_a and n/M
0.408 [(mm m²)/MJ]	Constant partially based upon water density and latent heat of vaporization	
105.028	Constant partially based on density and specific heat of air at constant pressure.	
0.067 [kPa /ºC]	Psychometric constant	

The calculations of the equation were made in MATLAB. In table 1 there are several parameters which cannot be seen in equation (6), (7) or (8). The reason for this is that the calculations were quite massive and to know more about the complete calculations using the Penman-Monteith equation, see the program code in Appendix C section: *Evapotranspiration*.

2.4.2 Evaporation pan

As previously mentioned; evapotranspiration is the sum of evaporation and plant transpiration. An evaporation pan measure pan evaporation which is higher than evaporation from a water surface. That is; the pan measures a slightly overestimated value of potential evapotranspiration. Therefore it was important to obtain a pan coefficient that could be used to estimate the potential evapotranspiration.

2.4.3 Construction of pan

Due to lack of materials the pan was constructed by a circular plastic tub with a green colour. The diameter was 50 cm and depth of the pan was 15 cm. The pan was placed horizontally on a platform built by a frame of planks filled with sand. The sand was drenched in water and pressed with new sand until the platform was strong enough to handle rain. The pan was placed onto the platform and filled with water to a height between 2 and 5 cm from the edge. On the top of the pan a small plank was placed horizontally as can be seen in Figure 17. A leveller was used to make sure that the plank was lying exactly horizontal. A hole had been drilled in the plank so that a small bolt with a large screw could be mounted to it. The screw could then be screwed down through the plank until the point where the tension of the water surface was broken. The height of the remaining part of the screw was measured with a Vernier calliper. In this way a precise measurement of the water height in the pan could be obtained.

Figure 17 Homemade evaporation pan located at El Centro

To get an idea of the size of the evaporation, the height of the water in the pan was supposed to be measured at the same time in two consecutive days. This proved to be a bit of a challenge since rain had a tendency to occur during the nights. However some measurements were carried out.

2.5 THE WATER BALANCE

2.5.1 Catchment and Land use for each station

The catchment area for each measurement station was calculated and classified, with the help of already existing maps at Iracambi. The boundaries of the catchment-areas were determined by using a topographic map and from the highest point drawing a line perpendicular to the height curve. Close to the measurement stations the lines were drawn towards the river, which is located at the lowest part of each catchment. Since the areas included a lot of hills and valleys, it was important to take these into account when determining the boundaries. Afterward the sizes of each catchment were calculated by putting a piece of parchment paper on top of the topography map and copying the boundaries of the catchment-areas. Afterwards the copied catchment areas were separated from each other and weighted on a regular scale with an accuracy of 5 decimals. By knowing the weight of one km^2 the dimension of each catchment could be calculated by dividing the weight of the catchment with the weight of one km^2. To further enable comparison between the catchments, each area was also classified according to 3 groups of land: pasture/grasslands, forest and mountains.

Since several flow measurements were done at all measurement stations the base flow at each measurement stations could be estimated. This data together with the catchment enabled calculations of the specific runoff, the runoff per unit area ($l/(km^2\ s^1)$), which gives an idea of the long-term water supply in the area.

2.5.2 The storage

The change in storage was calculated by rewriting the water balance equation (Equation 1, section 2) which gives:

$$\Delta S = P - Q - E \qquad (9)$$

The only measurement station where water flow could be calculated continuously was W2, where the pressure gauge was installed. The total discharged volume of water during the measurement period, 29th of February to 3rd of April 2012, was calculated for W2 in MATLAB by integrating the water flow over time. The catchment for this measurement station was calculated as described in section 2.5.1 and by dividing the discharged volume water with the catchment, the discharge in mm was obtained. Also the total precipitation and evapotranspiration during the same period was calculated in mm.

2.7 WAYS TO ENHANCE THE KNOWLEDGE AT IRACAMBI

According to the purpose of this report an important part of the project was to increase the knowledge of the hydrologic cycle at Iracambi research station. Another important part was to develop more reliable methods for Iracambi than their previously used methods. These methods had to be easy to use and to understand. The equipment and methods used in this project are low-tech and easy for Iracambi to use. An effort was made to leave instructions of both equipment and methods used in this project, examples of such instructions can be seen in Appendix D.

3 RESULTS

3.1 WATER FLOW

The water flow was measured at W8, W7, W5, W5a, and W2 frequently from the 29th of March until the 11th of April. The relation between the water depth and the water flow was found through the power equation (4). Each measurement station has a specific relation between the water depth and the water flow, therefore the power equation looks different for each measurement station. At the measurement station W2 the water depth was measured continuously with a pressure gauge, thus the water flow could be presented for the whole measuring period together with precipitation and temperature. The flow peak during the rain the 31th of March for W5, W5a and W2 is presented in the last section (3.1.3).

3.1.1 The stage-discharge relation

In Figure 18, the relationship between water depth and water flow is shown for W5. The flow measurements were made at seven different water depths, represented as red stars. The MATLAB program calculates the parameters of the power equation (4), so that the correlation at this measurement station can be described as:

$$Q = 3238 \cdot (h-0.21)^{1.28} \qquad [Q \text{ in l/s, } h \text{ in m}]$$

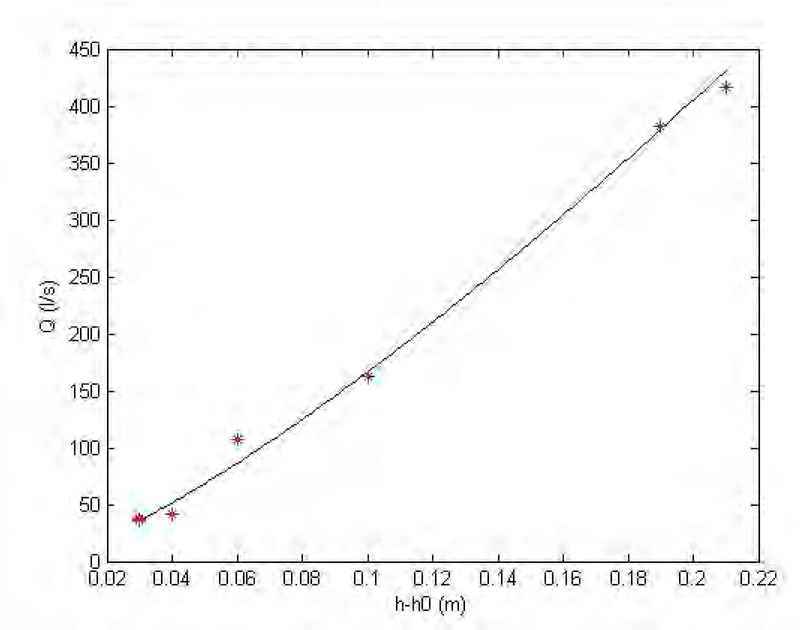


Figure 18 The relation between water depth and water flow for W5.

The relation between water flow and the water depth for W5a can be seen in Figure 19. The flow measurements were made at eight different water depths, which is represented as red stars in the figure. The power equation at this measurement station is:

$$Q=12869\ (h-0.05)^{2.43} \qquad [Q \text{ in l/s, } h \text{ in m}]$$

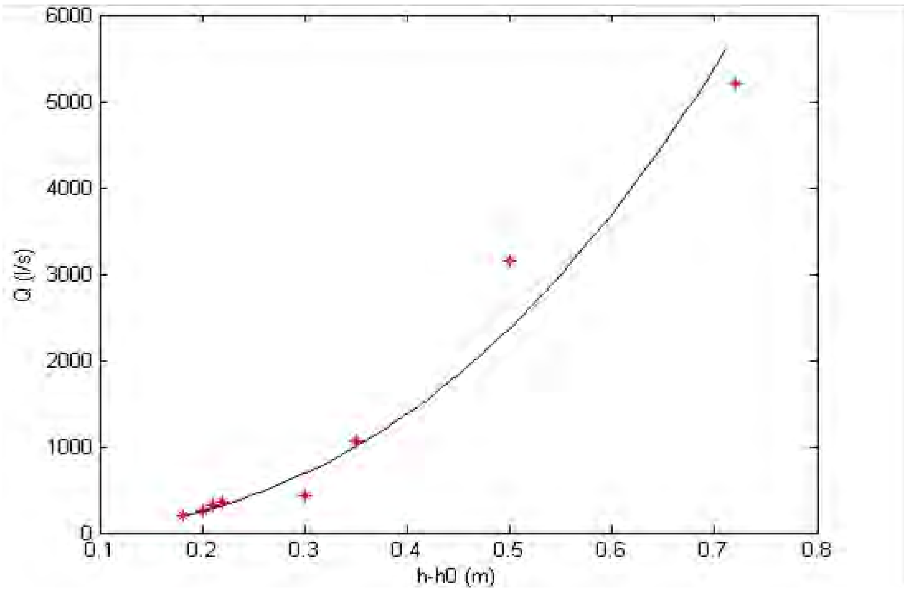


Figure 19 The relation between water depth and water flow for W5a.

Figure 20 shows the relationship for W2. The flow measurements were made at 15 different water depths, which are represented as red stars in the figure. The power equation at this measurement station is

$$Q=296\ (h-(-0.\ 6)^{3.\ 84} \qquad [Q \text{ in l/s, } h \text{ in m}]$$

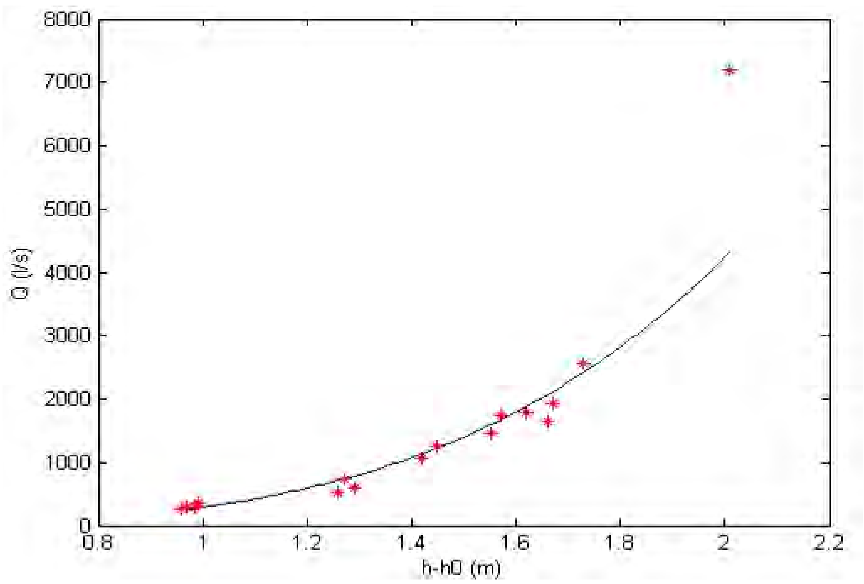


Figure 20 The relation between water depth and water flow for W2.

Two of the measurement station, W7 and W8 could not be used for the stage-discharge relation. The relation could not be found for water depths greater than around 0.3 m. In figure 21 the water flow at 6 different depths at W8 is shown as red stars, the figure also shows the curve that best fits the points. The power equation that corresponds to this graph is

$$Q=5803\ (h-0.05)^{1.82} \qquad [Q \text{ in } l/s,\ h \text{ in } m]$$

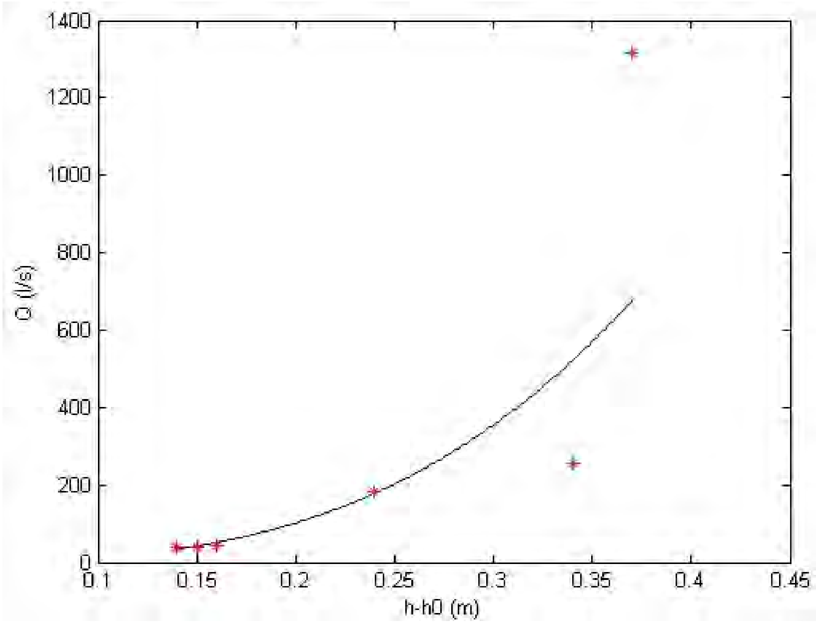


Figure 21 The blue curve represents the searched relation between water depth and water flow for W8.

3.1.2 Water flow, temperature and precipitation during the whole measuring period

Since the pressure gauge, placed at measurement station W2, registered the water depth and the temperature of the water from the 29th of February until the 3rd of April 2012, data is available continuously every 5 minute. From the calibration made between water flow and water level, the water flow could be calculated for every 5 minute. The flow is presented, together with the temperature of the water and the daily precipitation in, Figure 22.

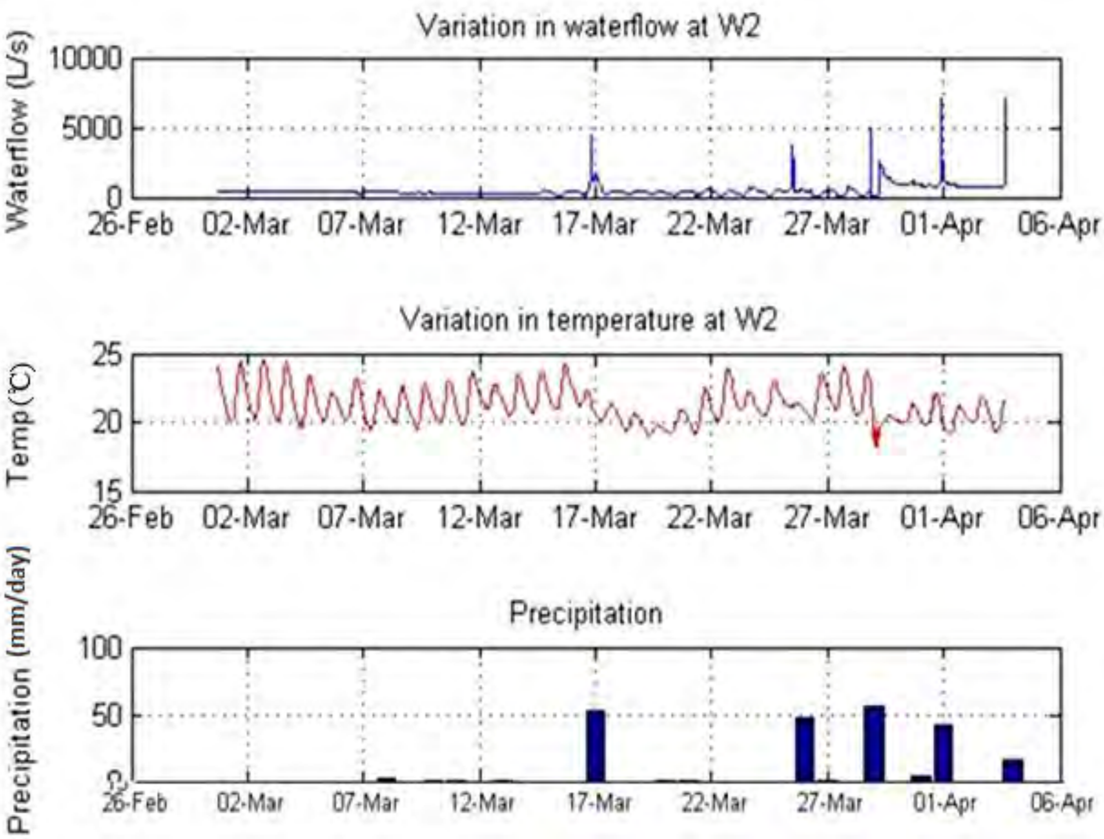


Figure 22 Water flow at W2, temperature of the water and precipitation from the 29th of February until the 3rd of April, 2012.

During the heavy rain the 27th of March and 3rd of April the stream became extremely strong and broke the bamboo-construction holding the pressure transducer. Fortunately, the data could be saved before and after the incident, but the largest flows remained unmeasured.

3.1.3 Flow peaks during the rain the 31st of March, 2012

The 31st of March it rained 35 mm from 07:40 PM to 08:30 PM. The following figures, Figure 23, Figure 24 and Figure 25, show the flow peak that could be observed at measurement stations W5, W5a, and W2. The runoff during and after the rain (07:00 PM 31st of March to 10:00 AM 1st of April) was calculated for each measurement station.

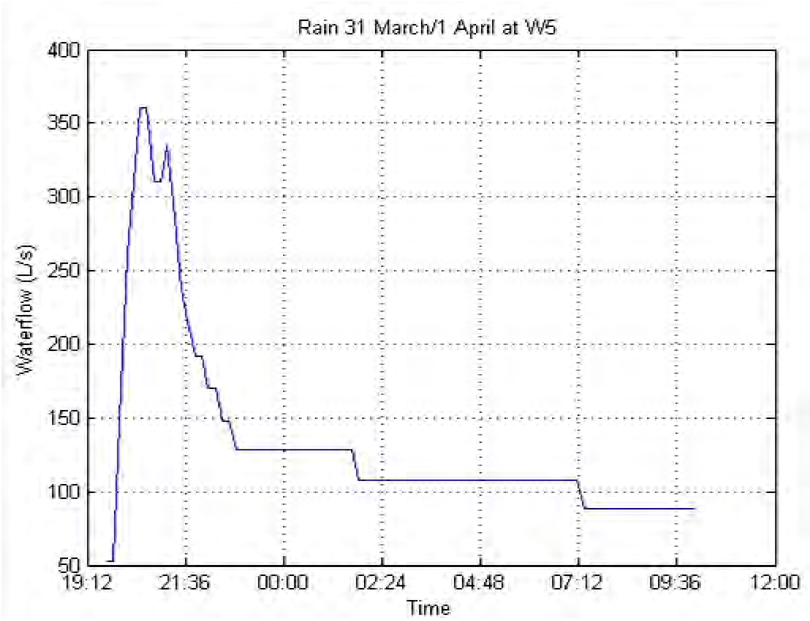


Figure 23 The flow peak during the rain at W5

The total runoff from 07:00 PM 31st of March to 10:00 AM 1st of April, was 3400 m^3 at W5.

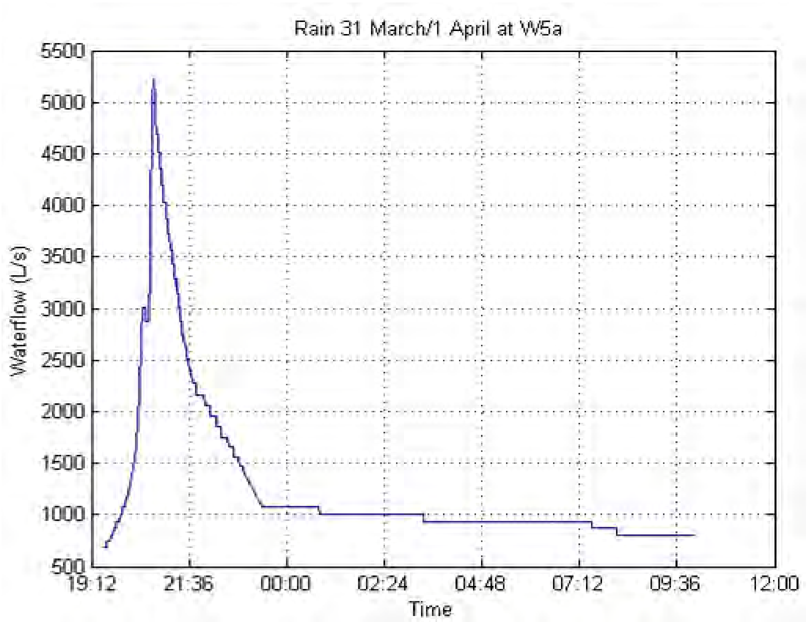


Figure 24 The flow peak during the rain at W5a.

The total runoff, 07:00 PM 31st of March to 10:00 AM 1st of April, at W5a was 27 100 m^3.

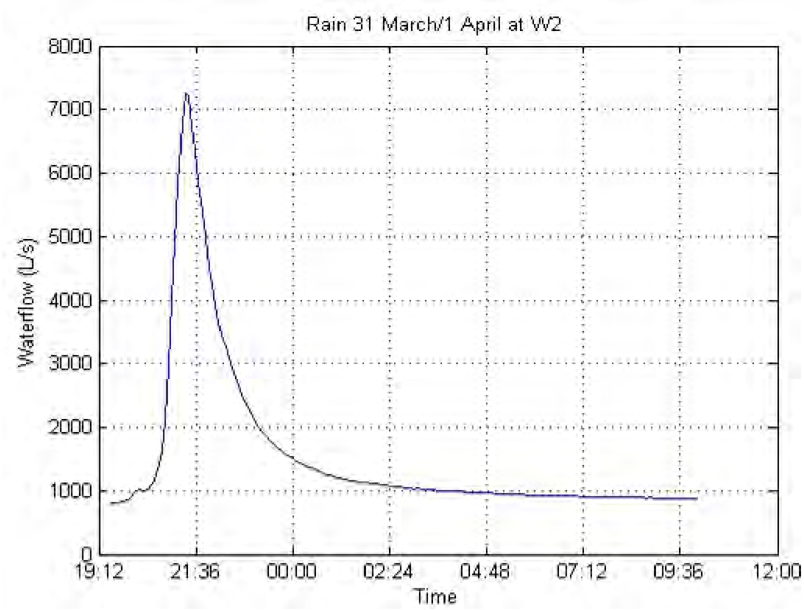


Figure 25 The flow peak during the rain at W2.

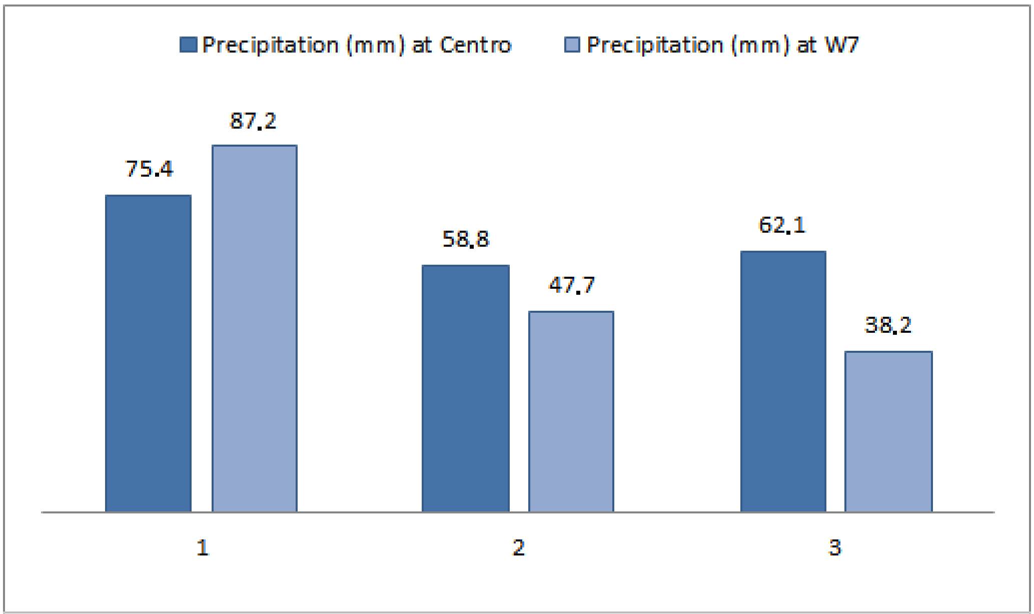
The total runoff from, 07:00 PM 31st of March to 10:00 AM 1st of April, was 37 500 m^3 at W2.

3.2 PRECIPITATION

The precipitation was measured manually at two different locations. The first measurement point was placed at El Centro. In Figure 26, the precipitation measured after the rains are presented. There was no measurable precipitation from the start of the measurements, 29th of February, until the 16th of March.

Figure 26 Precipitation measured at El Centro.

The other measurement point for precipitation was situated close to W7. Because of the distance the precipitation was not collected as frequently as at El Centro. The collected precipitations at W7 and at El Centro during the same time periods are shown in Figure 27. The date and time between each collection is also shown in the figure.



Periods

1.) starts: 2012-03-27 12:30 PM **ends:** 2012-03-30 06:30 PM

2.) starts: 2012-03-30 06:30 PM **ends:** 2012-04-03 06:05 PM

3.) starts: 2012-04-03 06:05 PM **ends:** 2012-04-11 11:30 AM

Figure 27 Comparison between the precipitations measured at El Centro and W7.

3.3 EVAPOTRANSPIRATION

Calculations of the Penman-Monteith equation were carried out in MATLAB, see Appendix C. As can be seen in Figure 28, the evapotranspiration for each region defined by rainforest, grasslands and open water was somewhere between 0.8 to 16 mm per day.

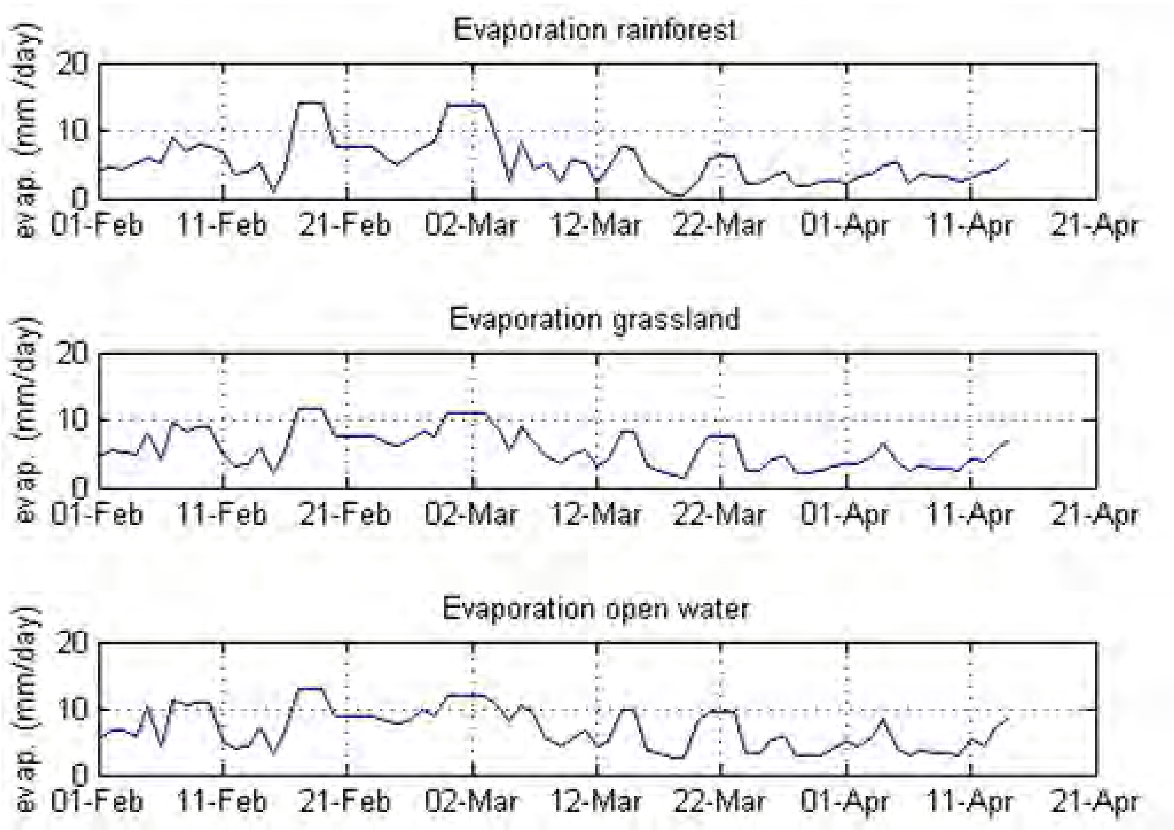


Figure 28 The daily average evapotranspiration from grasslands and forests as well as evaporation from open water.

The daily average for each month can be seen in table 2. As expected the open water evaporation is higher than the evapotranspiration for land covered by rainforest and land covered by grass.

Table 2 Daily average evapotranspiration for three different land uses

	Evapotranspiration Rainforest	**Evapotranspiration Grasslands**	**Evaporation Open water**
	Mean value per day [mm/day]	Mean value per day [mm/day]	Mean value per day [mm/day]
February	7.8	7.8	9.1
March	4.9	5.4	6.6
April	3.4	3.7	4.4

Table 3 shows the results of the measurements from the pan evaporation compared to the calculated evapotranspiration. The table also shows the weather conditions that dominated and the concerned dates.

Table 3 Comparison between the calculated evapotranspiration from the Davis data with the measured pan evaporation at El Centro.

Date	**Weather**	**Evap. rainforest** [mm/day]	**Evap. grassland** [mm/day]	**Evap. open water** [mm/day]	**Pan evaporation measured at El Centro** [mm/day]
2012-03-14	Sunny	7.6	8.3	10.0	18.0
2012-03-20	Sunny	2.6	5.8	8.1	13.4
2012-03-27	Overcast	4.0	4.6	5.6	7.2
2012-03-28	Overcast	1.8	2.3	2.9	1.2
2012-04-03	Semi-overcast 2 (Partially sunny)	3.6	4.4	5.5	6.5
2012-04-11	Semi-overcast 2 (Partially sunny)	2.9	4.0	5.3	6.3
2012-04-12	Semi-overcast 1 (Partially cloudy)	3.9	3.9	4.5	4.5

The table compares the measured pan evaporation with the calculated evapotranspiration. The pan evaporation follows the increases and decreases of the calculated evapotranspiration. And, except for the 28th of March, the pan evaporation was higher than the calculated evaporation from open water. However there are no trends, which mean that a pan coefficient cannot be calculated and the pan evaporation cannot be correlated to the evapotranspiration.

3.4 THE WATER BALANCE

For each measurement station the base flow, catchment area and specific runoff was calculated. Also, the land use was estimated for each of the different catchments, the data is shown in table 4.

Table 4 The base flow, catchment, land use and the specific runoff are shown for the five measurement stations.

Measurement station	**Base flow** [l/s]	**Catchment** [km^2]	**Land use**	**Specific runoff** [$l/(km^2\ s)$]
W8	40	1.7	Mountain/pasture	24
W7	150	6.9	Cultivated land/pasture	22
W5	40	1.6	Forest	25
W5a	200	10.9	Cultivated land/pasture/Forest	18
W2	310	13.8	Cultivated land/pasture/Forest	22

The total discharged amount of water during the measurement period, 29th of February to 3rd of April, was calculated for W2. Also the total precipitation and evapotranspiration during the same period were calculated. By using the equation for the water balance (Equation 9) the storage could be calculated, the results are shown in table 5.

Table 5 The total discharge precipitation, evapotranspiration and storage from the 29th of February to 3rd of April

Total volume discharged water [m^3]	**Total precipitation P** [mm]	**Total discharge Q** [mm]	**Total evapotranspiration E** [mm]	**Storage ΔS** [mm]
2 784 000	227	202	183	-157

As the table shows, there is a minus sign in front of the change in storage. This implies that during this period water was taken from the ground storage and either evaporated or drained out into the river.

In table 6, the effects of the rainfall the 31st of March (the same as described in section 3.1.2) are compared to the effects of the rainfall the 3rd of April at measurement stations W5, W5a and W2. The measurements began before the rain and ended when the water level was close to base level and were conducted during 15 hours. The total precipitation, evapotranspiration and discharge were calculated in mm for the two different days (during 15 hours not 24). From this data the storage in the catchment (interception, surface water, soil water and groundwater) could be estimated.

Table 6 The parameters in the water balance for the rain the 31th of March and the 3rd of April.

	Measurement station	Precipitation [mm]	Intensity of rain [mm/h]	Evapotransp. [mm]	Measured runoff [mm]	Surface storage [mm]	Surface storage [%]
31th of March 2012	W5	35.1	42.1	2.5	4.5	28.0	67 %
	W5a	35.1	42.1	2.9	6.1	26.1	62 %
	W2	35.1	42.1	2.9	6.2	26.2	62 %
3rd of April 2012	W5	16.4	12.3	3.6	3.4	9.4	76 %
	W5a	16.4	12.3	4.0	10.0	2.4	20 %
	W2	16.4	12.3	4.0	---*	---*	--*

** No value could be calculated because the pressure transducer broke during the rain.*

4 DISCUSSION

4.1 WATER FLOW

Water flow was measured at five stations along the river. The stations were chosen during very low flows and thereby without information about what effect heavy rain would have on each location. During some of the rains the water level could change dramatically within seconds, causing heavy erosion and alteration of the bottom composition. Further on, the overall terrain posed some very time-consuming difficulties, and flooding prevented passage at several occasions. Consequently each measurement station presented challenges for implementing a monitoring program.

Reaching the measurement stations furthest upstream, W8 and W7, consumed a lot of time. Hence, the stations were not possible to reach during the heavy rains and the impacts on the stream during such occurrences were not observed. Although neither W8 nor W7 could be reached daily, staff gauges were placed at these stations. Furthermore these two measurement stations did not seem to have the perfect physical properties to fulfil the searched stage-discharge relation, i.e. the relationship between water level and water flow as presented in equation (4). As expected, it was discovered after the first intense rain that no relation between water flow and water level could be found for high flows. The change in water level at W8 was negligible when the water flow rose over 250 l/s; this happened at a water depth around 0.3 m (see Figure 21, section 3.1.1). The reason for this was probably that new passages for the water became accessible when the water level and water flow increased. The heavy floods washed away the staff gauge at W7, and since the same problem with new passages for the water was noticed, replacing it seemed to be too much of a time waste. However, both measurement stations, especially W7, were very suitable for the method of slug injection. There was no problem in finding an injection point and the rocky bottom composition mixed the water thoroughly.

The W5 was the only station on a tributary. It was chosen due to its close location to El Centro, and the fact that the catchment completely consisted of forest. The station was an acceptable place to use a current meter. However, the instant slug injection was much more suitable. Since a relation between water level and water flow was found (see Figure 18, section 3.1.1) it was possible to get flow data using a staff gauge, thus the effects of rain could be observed. In general, the area had hardly any response to smaller rains, and reacted slower than the main stream to heavier and more intense rains. These two characteristics were expected and the station seems to be a very representable place to conduct regular flow measurements.

The W5a was non-existent before the start of this project. It turned out that this was to be one of the most suitable measurement stations for constant surveillance of the river flow. This is partially due to its location close to El Centro, and partially because of its physical properties. During base or lower flows the current meter could be used successfully, and during higher flows the method of slug injection could be used equally well. Thus, the flow in this part of the stream can be monitored at all times. Furthermore, at this station the relation between water level and water flow was accurate enough (see Figure 19, section 3.1.1) to monitor the water flow by just using the staff gauge. This, in combination with the great accessibility, made the measurement station the place where the reaction to large and intensive rains could be observed. Interestingly, the station was monitored during increasing water levels at a rate of 1-2 cm per second and the staff gauge could quite accurately be used to give flows in the range of 40 l/s up to around 5000 l/s. This makes this station a fairly good schoolbook example of where flow measurements should be conducted.

The measurement station furthest downstream, W2, was equipped with the pressure gauge. At several times during the project, the station was not only unreachable during the floods but also demolished at two occasions. The bottom composition consisted mostly by sand and changed with the characteristics of the water flow. Also the sides of the river were also heavily affected by erosion. Thus, the complete cross-section changed and a lot of time was invested to track these changes. In spite of these problems, a relation between the water depth and the water flow could be found (see Figure 20, section 3.1.1). The relation is however inaccurate during very high flows. As the flooding prevented passage, only one flow measurement could be conducted when the water level was as high as 2 m. This measurement took place in the middle of the night and the technique used was instant slug injection. Hence, there is quite a possibility that the amount of salt was inaccurate due darkness and fatigue that resulted in human error. Other reasons for an inaccurate value could be that the river flow was too large to be measured with slug injection or that the velocity was too high causing incomplete mixing of salt and water. Due to its accessibility the measurement station W5a would have been a more suitable place to install the pressure gauge.

All in all, the method of instant slug injection is a better way for Iracambi to measure river flow. The staff gauge also gives a good estimation of the river flow at measurement station

W5, W5a and W2 and could be used for daily registration of the water flow. Even though all stations could be used for river flow measurement, W5a was by far the best.

4.2 PRECIPITATION

When the plan for this project was lined out, two assumptions were made which turned out to be wrong. Firstly, the project was supposed to take place during the rainy season that usually extends from the end of October to the beginning of March, with the yearly precipitation peak occurring during January and February. In the year of 2012, February was an unusually dry month and the precipitation peak was delayed by approximately two months. This occurrence had several effects on the project.

Firstly, the investigations of plausible measurement stations for river flow took place when the water was marginally above the base depth. Thus the measurement stations were selected without knowledge of how the rivers reacted to rain and large flows. As a result some of the chosen stations where hard to reach during heavy rains and others experienced erosion and changes of the bottom composition. Some data were also lost as the turbulence of the water destroyed some of the bamboo measurement stations.

Secondly, the precipitation was initially expected to be distributed fairly equally over the area, thus only two measurement points were used for data collection. However, due to the mountains, hills and valleys in the area, it was discovered after some measurements and observations that this is not the case in Graminha Basin. Some local rains that only covered a small part of the basin but still had a massive impact on the river flow occurred during the measurement period. For instance there is a local phenomenon in the area during which very low clouds are forced up over the higher mountain peaks, allowing water vapor to condense and releasing huge amounts of rain in the process. The rain hit the mountain sides, but the resulting direct-runoff caused the river flow to rise extremely rapidly. Therefore it was not possible to collect a considerable amount of the perception affecting the flow, making the estimation of the water balance highly questionable.

The results from the comparison between the two measurement points for precipitation (see Figure 26, section 3.2), shows a difference in precipitation between 14 % and 39 %. The difference can partially be explained by the method and location of the collection. But it also indicates that the precipitation is not equally distributed over the area which agrees with the observations made during the project. It was concluded during the project that Iracambi can use low-budget rain gauges to get a hint of the amount of rain affecting the area, but to carry out correct measurements high-tech equipment is needed.

4.3 EVAPOTRANSPIRATION

Evapotranspiration is by far the most difficult factor to assess, and the two methods used yielded two very different results. This is partly due to the fact that the Penman-Monteith equation estimates *actual evapotranspiration* and the evaporation pan measures *pan evaporation.* Also, the pan evaporation should be higher than the actual evapotranspiration from open water. However, the outcome of this project was that there was no correlation between the two. This result might be explained by several assumptions made during implementation of the two methods.

The Penman-Monteith equation is based on a large range of empirical and theoretical data. The parameters measured on-site were dew point, wind speed and temperature. These measurements are dependent on the precision of the Davis machine. Further on, the dewpoint and temperature were also used to calculate the relative humidity, and therefore there is a large risk of accumulated errors in this parameter. On-site, estimations of cloudiness for each day were made through observation and this is the parameter that is the most sensitive to the factor of human error. The other parameters were based on standard values and the specific conditions in Graminha basin were not really taken in consideration.

Several assumptions had to be made to enable the construction of the evaporation pan, thus risking the reliability of the measurements. The pan evaporation follows the increases and decreases of the calculated evapotranspiration (see table 3, section 3.3), but there are too few conducted measurements to make any conclusions about the relation between open water evapotranspiration calculated with the Penman-Monteith equation and the measured pan evaporation. This means that no pan coefficient could be found.

After a while, questions about the appropriateness of using an evaporation pan in tropical environments were raised. Except for the rainy nights, Iracambi is frequently visited by young students taught in school not to leave any water in any receptacle in order to prevent spreading of dengue fever. Dengue fever is a disease spread by mosquitoes that breed in non-turbulent water, thus information campaigns in all areas of Brazil inform the residents that water in any type of vessels can help spread the mosquitoes and thereby also the disease. Not only were a lot of mosquito larvae found in the evaporation pan, but the method can also be counterproductive when fostering young students to take responsibility to prevent the spreading of dengue.

Finally, the deviation in weather from historical average also makes it hard to compare the results from this project with other weather data. However the project shows that an estimation of evapotranspiration on site is possible with the data collected by the Davis machine plus some daily observations of the weather.

4.4 THE WATER BALANCE

The previous parts of the discussion have addressed the problems and errors of the measurement methods used. These errors accumulate in the calculation of the water balance and must be taken into consideration when evaluating the results. The evaluation of the water balance makes it possible to assess whether the water storage in the ground increased or decreased during the project.

Table 5 (section 3.4) concludes that during the time of the project, 157 mm of water were lost from the ground storage. Considering that this period is supposed to be the rainy season it should be the opposite. But since there were very few rains during the measuring period and mostly warm and dry days this could be the explanation to why water is taken from storage instead of increasing the storage. The water leaving the ecosystem as water flow in the river is probably very close to the true value, hence for ΔS to be a positive value, i.e. an increase in the water storage, either the precipitation should have been higher or the evapotranspiration should have been lower. With only two measurement points, the difference in precipitation between the areas was not considered and the real precipitation could have been much higher than what was calculated since observations of rain in other areas were made (section4.2). Further, for the storage to be a positive value the calculations of precipitation and evapotranspiration must be so large that the calculated decrease in storage during this period is quite likely. Even though *the size* of the change in storage is uncertain, the indication is that the storage decreased during the project.

The comparison between the rains the 31st of March and the 3rd of April shows that the surface storage was largest in the catchment of W5 for both of the rains (see table 6, section 3.4). This result was to be expected since the area is characterized by forest and suggests that leaves and other vegetation have intercepted the rains. Table 6 also shows that the rain during the 31st of March increased the storage much more than the rain the 3rd of April for the area of W5a. In the area of W5a, 62 % of the precipitation was stored during the rain the 3rd of April, only 20 % was stored during the rain the 31^{st} of March. Since the intensity of the rain the 31^{st} of March was much higher (42.1 mm/h) it should have resulted in a much higher runoff, than the rain the 3^{rd} of April (12.3 mm/h), and hence a lower level of change in storage. If the numbers are accurate, this can be explained by the rainy weather that preceded the 3^{rd} of April made the ground saturated. Another explanation is that the clouds were pressing towards the mountain tops (the 3^{rd} of April), thus releasing a lot of rain that was not measured. However, the effect of more rainfalls in Graminha basin needs to be studied to be able to make any conclusions about the correlation between land use and water supply.

In table 4 (section 3.4) it can be seen that the specific runoff from the area of W5 was the highest (25 l/(km^2 s)), followed by the specific runoff from the area of W8 (24 l/(km^2 s)), and (22 l/(km^2 s)) from W7 and W2. The catchment of W5a had the lowest specific runoff (18 l/km^2 s)). Specific runoff is the difference between precipitation and evapotranspiration in an area (Naturvårdsverket 2009), which is also dependent on the unique topography, climate and vegetation of the area. Under natural conditions, without human intervention, the specific runoff can be a good benchmark for the groundwater recharge in the superficial layers of the ground, especially in areas where surface runoff does not occur. It was discovered during the project that surface runoff occurs in the Graminha basin area, which makes it difficult to make any conclusion about the recharge of groundwater, also because two months observation is a too short time period for such conclusion. Further, the specific runoff in this project is calculated from the base flow. However, the calculated specific runoff for the different areas gives an indication of where most groundwater is recharged.

4.5 EFFECT ON THE IRACAMBI WORK

Iracambi has been working on measuring the flow velocity using an orange as a float. This method is easy and can be used to measure the flow in a river with non-turbulent flow. However, in mountain rivers where turbulent flow can be expected, this method is less than suitable. The method of instant slug injection was previously unknown to Iracambi. Estimation of the river flow with a staff gauge was also a method that had not been used at Iracambi research station, thus an effort was made to increase the understanding of this method. This was done by making a manual that is easy to understand with pictures and photos of the measuring methods and the equipment, see Appendix D. Also excel sheets with formulas that calculate water flow and evaporation from the measured values has been constructed and saved at the database at Iracambi. The idea is that the methods in the sheets will be used at Iracambi and thus enable understanding of the water balance in the long-term perspective as well as enable future conclusions about the effect of land use on the ecosystem.

5 CONCLUSION

This project came to the conclusion that the special conditions in the Graminha basin makes it unsuitable for low-budget estimations of the water balance. However, the methods presented in this project can be used at Iracambi research station to facilitate observations of hydrological fluxes in the area.

The station at W5a is a favourable place for future measurements of the water flow and the method of slug-injection can be used favourably in most parts of the river and its tributaries. The precipitation should be measured with higher accuracy to obtain a better estimation of actual amount. The Penman-Monteith equation can be used to calculate the size of evapotranspiration, but further studies and efforts should be carried out in order to improve the parameters.

The calculations of the water balance indicate that the water storage decreased during the time of the project. Based on the flow measurements and observations the conclusion can be made that the area characterized by forest was less affected by floods than the areas covered by grass. The area characterized by forest had a larger specific runoff during the 10 weeks of study. Since the specific runoff is based on base flow and evapotranspiration is generally higher, the higher runoff can either be explained by a comparatively high precipitation affecting this area or the area experienced a large decrease of groundwater storage. There were no observations that could confirm the former and the latter might be a result of relatively large water storage, which is a generally expected advantage of vegetation. Hence, there was plausible evidence that the area covered by forest has a larger potential of groundwater recharge.

Since the unstable weather conditions cause severe erosion and flooding in the Graminha basin, the indications that the areas covered by forest are better at buffering against both drought and heavy rains can be used as an argument for Iracambi to initiate implementation of payment of environmental services.

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APPENDIX A

The conductivity was related to the concentration of salt through calibration. As can be seen in the graph below, the correlation had a an R-squared of 0, 9991, which indicates that the derived connection between the salt and the conductivity can be trusted.

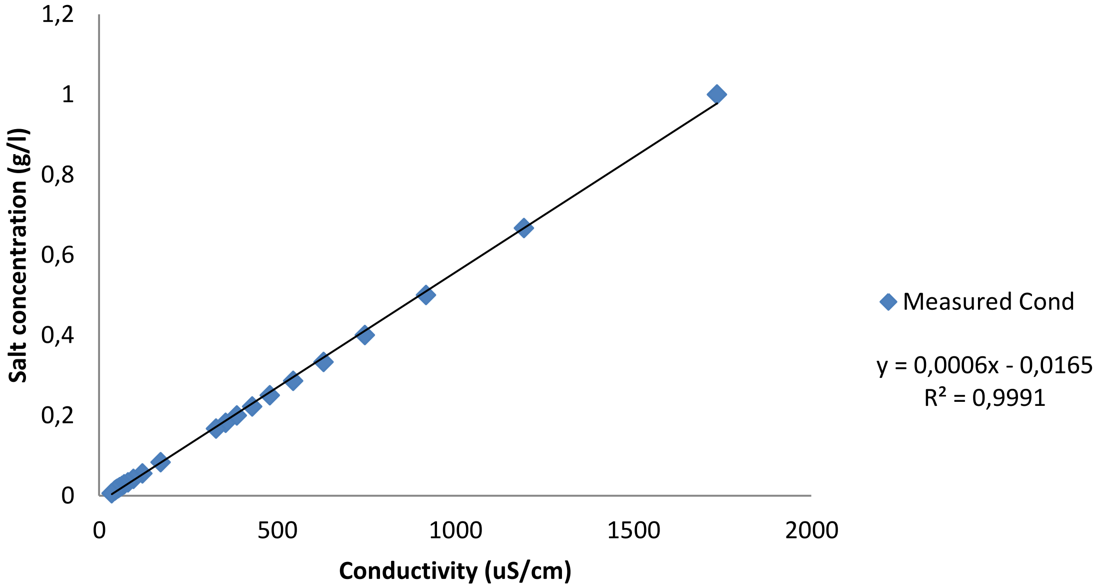


Figure 29 Conductivity calibration.

APPENDIX B

The 29th of February 2012, calibrations were made to correlate the pressure to the height of the water table, as presented in the graph below. As can be seen the correlation has an R-squared value of almost one, which suggests that the correlation can be trusted.

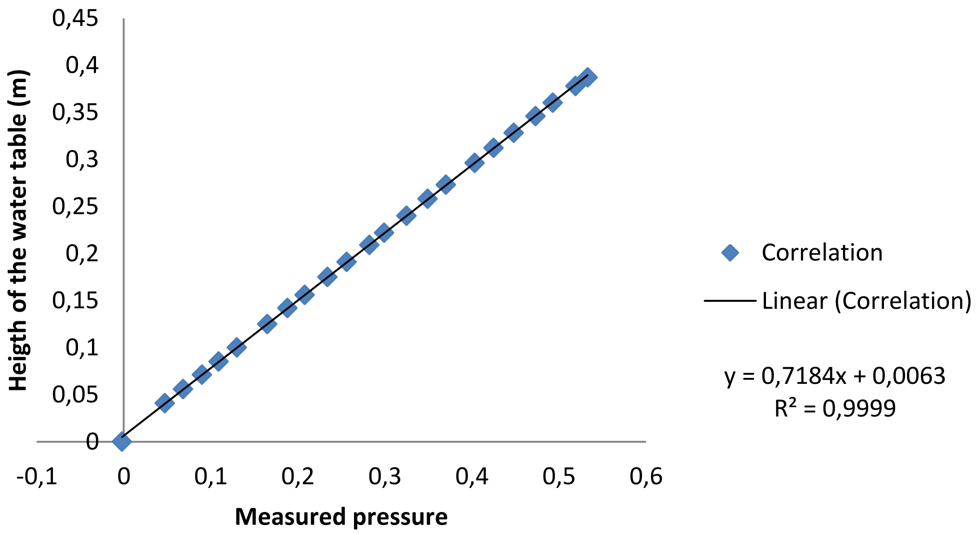


Figure 30 Pressure-water depth calibration.

APPENDIX C

This appendix contains the program code created in MATLAB to calculate the water flow using a current meter as well as slug injection, followed by the code used to calculate the actual evapotranspiration using the Penman-Monteith equation. Finally the code created to calc la te the water balance s presente . The re en text marke w th a '%'- sign is text that has no impact on the code, and is used to describe the different commands of the program.

Flow measurement using current meter

```
%The following program code is an example of how the velocity area was
applied after measurements with a current meter. Since the measurement data
had to be inserted manually and the water level changed from time to time,
and sometime the width was also changed, several alterations had to take
place for each measurement conducted. However the following was used as a
blue print.

% Each measurement station where the current meter was used was divided
into sections. In this example the sections started 60 cm from the river
bank and with one meter interval, also ended 25 cm from the other river
bank (The river was 5.85 meters wide). Afterwards the waters velocity was
measured at different depths for each section. This program calculates the
combined velocities for each section and depth, which is simply referred to
as the flow.

%First the different measurement depths must be recorded. This is done by
creating a matrix which contains the measurement depths for each section.
YY=cell(6,1);                                % Creates a matrix containing
                                             only zeros, with six rows and 1
                                             column.

% The following are the values for the row vectors that will constitute
matrix YY. The depth starts with zero and ends with zero to enable
calculation of the cross-section area of the measurement station. Further
on the depth values start from furthest from the bottom and ends closest to
the bottom.
YY{1}=-[0 0.35 0.30 0.20 0.10 0];            % Measurement depths at section
                                             60 cm from the river bank. Note
                                             that the depths go from highest
                                             point to lowest.
YY{2}=-[0 0.42 0.37 0.35 0.30 0.20 0.10 0]; % Measurement depths at section
                                             160 cm from the river bank.
YY{3}=-[0 0.40 0.35 0.30 0.20 0.10 0];       % Measurement depth at section
                                             260 cm from the river bank
YY{4}=-[0 0.45 0.40 0.35 0.30 0.20 0.10 0]; % Measurement depth at section
                                             360 cm from the river bank.
YY{5}=-[0 0.55 0.50 0.40 0.35 0.30 0.20 0.10 0]; % Measurement depth at
                                             section 460 cm from the river
                                             bank.
YY{6}=-[0 0.59 0.54 0.50 0.40 0.35 0.30 0.20 0.10 0]; % Measurement depth
                                             at section 560 cm from the river
                                             bank.

% In a similar way as before, a matrix will be created which contains the
values for the measured velocity at each depth for each section.
```

```
XX=cell(6,1);                                   % Creates a matrix containing
                                                only zeros, with six rows and 1
                                                column.

% Each row within the matrix XX, will have the following values. The values
are the velocity measured at each depth beginning with the depth furthest
from the bottom at the section closest from the same river bank as before.
XX{1}=[0 0 0 0 0 0];                            % The measured velocities for
                                                each depth at section 60 cm from
                                                river bank.
XX{2}=[0  0  0.0085  0.0193  0.0625  0.1110  0.1241  0.1241]; % The measured
                                                velocities for each depth at
                                                section 160 cm from river bank.
XX{3}=[0  0  0.1361  0.2059  0.2171  0.2215  0.2215]; % The measured velocities
                                                for each depth at section 260 cm
                                                from river bank.
XX{4}=[0  0  0.1215  0.1305  0.2181  0.2411  0.2517  0.2517]; % The measured
                                                velocities for each depth at
                                                section 360 cm from river bank.
XX{5}=[0  0  0.0595  0.1436  0.1488  0.1491  0.2064  0.2303  0.2303]; % The
                                                measured velocities for each
                                                depth at section 460 cm from
                                                river bank.
XX{6}=[0 0 0.0007 0.0193 0.0318 0.0779 0.0674 0.1042 0.1299 0.1299]; % The
                                                measured velocities for each
                                                depth at section 560 cm from
                                                river bank.
% A figure is created in which the velocity for each depth for each section
can be seen
figure(1)
for i=1:6
   Area(i)=polyarea(XX{i},YY{i});
   subplot(2,3,i);plot(XX{i},YY{i});
   title('Velocity for each depth')
xlabel('Velocity (m/s)')
ylabel('Depth (m)')
end

% A new figure is created which contains a plot of the total flow for each
section of the river.
figure(2)
x = [0 .60 1.60 2.60 3.60 4.60 5.60 5.85]; The X-axis is created which has
                                                the distance in meters for each
                                                section beginning closest to the
                                                river bank
plot(x,[0 Area 0], 'r-')                        The Y-axis, the total flow for
                                                each section, is plotted against
                                                the x-axis.

title('Flow for each section')
xlabel('Section(m)')
ylabel('Flow(m2/s)')

% By using the command ’polyarea’, the area under the graph in figure (2)
can be calculated. This means that the following calculates the combined
flow, for the entire cross-section in m3/s
Qh = polyarea(x,[0 Area 0]);

%Recalculates the flow to another unit [l/s]

Qcm = Qh*1000
```

Flowmeasurent using instant sluginjection

```
% The following program code is an example of how flow measurements using salt dilution (instant slug injection)was applied. A bucket with a predetermined concentration of salt was injected into the river, and the change of conductivity was measured downstream. The measurement period started before the injection was carried out to determine the baseline values, and ended when the conductivity returned to these values. In this way, a wave of increased conductivity could be observed in the display of the meter.

%Prior to the calculation in this program, the measured conductivity was recalculated into measured concentration. This was done by using the calibration result from appendix A. By doing this the wave could be observed as before, but with the unit[mg/l]. To calculate the flow the wave had to be recreated within the program. Afterwards the area beneath the curve could be calculated, resulting in a value with the unit [mg/l*s]. Finally, the added amount of salt was divided with the value to get the flow.
load saltutspadning_rakan_245_cm.txt        %Loading the textfile containing the measured concentration calculated from conductivity measurements at site. The values below the baseline has formerly been subtracted.
cond.=saltutspadning_rakan_245_cm;
% Creating a row vector that has the same amount of values as the calculated concentration. Since one measurement was taken for each second, this vector can be used as a time vector where each value symbolizes a second
z=length(cond.);
t=[1:z];

% Creating a figure where the concentration is plotted against the time in seconds. Hence, the physical passing of the salt wave can be observed in the graph.
figure(1)
plot(t,cond.)
xlabel('Time (s)')
ylabel('Salt concentration (mg/l)')

% By using the command 'polyarea', the area within the blue lines in figure (4) can be calculated(polyarea(X,Y) returns the area of the polygon specified by the vertices in the vectors X and Y). This means that the salt concentration for the whole measurement period can be calculated.
sek=L';                                     % The time vector must be transformed into a cloumn vector first
COND= (polyarea(sek,cond.));                % A value with the unit mg*s/l is calculated

% The values from the bucket must be added to the program to enable calculation of the flow.
V=7;                                        % The volume of the water in the bucket[l]
C=50000;                                    % Salt concentration in the bucket [mg/l]

Q=(C*V)/COND                                % The calculated flow in l/s for the measurement station
```

Evapotranspiration

```
% The following is the program code created in Matlab to calculate evaporation for each day during project, by using the Penman-Monteith equation.

% A text file with measured Temperature(C∘) for each day was loaded into the program
load temperaturevapo2.txt;
T = temperaturevapo2;

% A text file was loaded into the program, containing the calculated relative humidity for each day. These values are based on measurements of dew point and temperature for each day.
load relativluftevapo2.txt;
RH = relativluftevapo2;

% A textfile containing the cloudiness factor, an estimated value from observations of the weather, for each day was loaded into the program. The different types of weather for each day was classified into 4 different categories.
           Over cast = 0.05
           Semi-overcast 1(Partially cloudy) =0.25
           Semi-overcast2 (Partially sunny) = 0.5
           Sunny = 1.0
load solfaktorevapo2.txt;
nm = solfaktorevapo2;

% A text file with incoming shortwave radiation incident at top of earth atmosphere based on latitude and day of year. (Physical hydrology, figure B2.12.2).
load stralningevapo2.txt;
So = stralningevapo2;

% A text file with the date for each day during the project
load datumevap2.txt
datum = datumevap2

% The following values for aerodynamic resistance (ra), are estimated from table 2.1(Physical hydrology, page 41).
ra1 = 8;                   % ra1 = aerodynamic resistance for rainforest (usually between 5-10)
ra2 = 60;                  % ra2 = aerodynamic resistance for grassland (usually 50-70)
ra3 = 120;                 % ra3 = aerodynamic resistance for open water(usually 110-125)

% The following values for surface resistance (rs), are estimated from table. 2.1 (Physical hydrology, page 41)
rs1 = 100;                 % rs1 = surface resistance for rainforest (usually 80-150)
rs2 = 60 ;                 % rs2 = surface resistance for grassland(usually 40-70)
rs3 = 0 ;                  % rs2 = surface resistance for open water

% Following values for albedo are collected from website (http://agsys.cra-cin.it/tools/solarradiation/help/Albedo.html)
alb1 = 0.12;               % alb1 = albedo for rainforest
```

```
alb2 = 0.26 ;                  % alb2 = albedo for grasslands, high season interval or non-cultivated fields (0.17-0.28)
alb3 = 0.12;                   % alb3 = albedo for open water with sun angel of about 20 degrees.

% The parameters below are just zero vectors awaiting calculated values
es = zeros(1,length(T));       es= saturation pressure

ea = zeros(1,length(T));       ea= actual vapor pressure

Gr = zeros(1,length(T));       Gr= gradient of the saturation pressure curve
Sn1 = zeros(1,length(T));      Sn1= incoming shortwave radiation at the earth's surface defined by rainforest
Sn2 = zeros(1,length(T));      Sn2= incoming shortwave radiation at the earth's surface defined by grassland
Sn3 = zeros(1,length(T));      Sn3= incoming shortwave radiation at the earth's surface defined by open water
Ln = zeros(1,length(T));       Ln= incoming longwave radiation at the earth's surface.
Rn1 = zeros(1,length(T));      Rn1= net radiation at the earth's surface defined by rainforest
Rn2 = zeros(1,length(T));      Rn2= net radiation at the earth's surface defined by grasslands
Rn3 = zeros(1,length(T));      Rn3= net radiation at the earth's surface defined by open water
Ea1 = zeros(1,length(T));      Ea1= actual evaporation defined by rainforest
Ea2 = zeros(1,length(T));      Ea2= actual evaporation defined by grasslands
Ea3 = zeros(1,length(T));      Ea3= actual evaporation defined by open water

% The following is a loop(a for-loop), which calculates values for the pre-mentioned zero vectors

for i = 1:length(T);

% Calculation of saturation pressure [kPa]
es(i) = 0.6108*exp((17.27*T(i))/(237.3+T(i)));

% Calculation of actual vapor pressure [kPa]
ea(i) = es(i)*RH(i);

% Calculation of gradient of the saturation pressure curve[kPa/˚C]
Gr(i) = (4098*es(i))/((237.3+T(i)).^2;

% Calculation of incoming shortwave radiation at the earth's surface defined by the different types of landuse[MJ/m2day]
Sn1(i) =(1-alb1)*(0.25+0.5*nm(i))*So(i);
Sn2(i) =(1-alb2)*(0.25+0.5*nm(i))*So(i);
Sn3(i) =(1-alb3)*(0.25+0.5*nm(i))*So(i);
```

```
%Calculation of incoming longwave radiation at the earth's surface. [MJ/m2day]
Ln(i) = (4.903*10^(-9))*(T(i)+273.2).^4.*(0.34-0.14*sqrt(ea(i)))*(0.25+0.75*nm(i));

% Calculation of net radiation at the earth's surface defined by the different types of landuse[MJ/m2day].
Rn1(i) = Sn1(i)+Ln(i);
Rn2(i) = Sn2(i)+Ln(i);
Rn3(i) = Sn3(i)+Ln(i);

% Calculation of actual evaporation defined by the different types of landuse [mm/day]
Ea1(i) = 0.408*((Gr(i)*Rn1(i)+((105.028*(es(i)-ea(i)))/ra1))/(Gr(i)+0.067*(1+(rs1/ra1)))) ;
Ea2(i) = 0.408*((Gr(i)*Rn2(i)+((105.028*(es(i)-ea(i)))/ra2))/(Gr(i)+0.067*(1+(rs2/ra2)))) ;
Ea3(i) = 0.408*((Gr(i)*Rn3(i)+((105.028*(es(i)-ea(i)))/ra3))/(Gr(i)+0.067*(1+(rs3/ra3)))) ;

% Since the actual evaporation has been calculated for each type of landuse and for each day during project the loop is ended
end

% Creation of the figures that will be represented in the project report, since further explanation of program code is uninteresting for the project these are not furthered explained.
t= length(T);
dag = [1:t];
d = datumevap2;
tidb=datenum(d(:,1),d(:,2),d(:,3));

Ea1
Ea2
Ea3
Ea11 = Ea1';
Ea22 = Ea2';
Ea33 = Ea3';

subplot(3,1,1);plot(tidb,Ea1)
title('Evaporation rainforest')
%xlabel('day')
ylabel('evap. (mm /day)')
datetick('x','dd-mmm','keeplimits','keepticks')
grid

subplot(3,1,2);plot(tidb,Ea2)
title('Evaporation grassland')
%xlabel('day')
ylabel('evap. (mm/day)')
datetick('x','dd-mmm','keeplimits','keepticks')
grid

subplot(3,1,3);plot(tidb,Ea3)
title('Evaporation open water')
%xlabel('day')
ylabel('evap. (mm/day)')
datetick('x','dd-mmm','keeplimits','keepticks')
grid
```

Program calculating the water balance

```
% This program was created to calculate the water balance and thereby
determine the size of the water storage. The measured parameters for this
calculation are flow at w2, evaporation from grass- and forestlands, and
manually measured precipitation. Prior to the use of this program,
textfiles containg the values for each parameter and for each day, was
created.

% A textfile containing the flow at measurement station w2 was loaded into
the program. The data was recalculated from the measured pressure to height
of the watertable by using the calibration relationship found in appendix
B. By correlating the height with manual flow measurements, the flow
measurements from the entire project period was created.
load flodeW2mod.txt
c=flodeW2mod;

% A textfile containing the calculated evaporation for each day was loaded
into the program. The textfile with this data came from the program already
presented in this project.
load evapperday.txt

evapgras=evapperday(:,4);          % The textfile contained the
                                   evaporation from grasslands in
                                   column 4, which was retrieved.
EvapG=sum(evapgras);               % The total evaporation from
                                   grasslands was summed up.
evapforest=evap29till3(:,5);       % The textfile also contained
                                   the evaporation from rainforests
                                   in column 5, which was
                                   retrieved.
EvapF=sum(evapforest);             % The total evaporation from
                                   rainforests was summed up.
Evap=(EvapG+EvapF)/2;              % The evaporation for each day
                                   and for the complete basin was
                                   approximated to be a mean value
                                   of this two types of
                                   evaporation.
%The values of the manually measured precipitation was inserted into a
textfile, which was afterwards loaded into this program

load precipitation.txt
pre= precipitation

Pre=sum(pre);                      % The total precipitation for
                                   the complete duration of the
                                   project was summed up.
Pretot=sum(pre)/1000;              % Precipitation was recalculated
                                   into meters
% The basin area was calculated by the method described in the project.
Area=13800000;                     % the calculated runoff area[m2]

% The total volume of precipitation for the entire area was calculated[m3]
Vol=Area*Pretot;

% The total volume of evaporation for the entire area was calculated[m3]
Evap_m3=Evap*Area/1000;
```

```
% To calculate the total volume of water measured at W2, the flow needed to be plotted against time. The volume is the integrated area under the graph which can be calculated as before of the command 'polyarea'.
cc=[0;c;0];
time=[1:length(cc)]';

Dischargedvolume= (polyarea(time,cc)*10*60)/1000;     %Since the presure gauge at W2 only took measurements every ten minutes, the multiplication with 10*60 results in the time unit of seconds. Divination by 1000 is simply to change the unit from L/s to m3.
Q=Dischargedvolume*1000/Area;

% The calculations was presented in the Matlabprogram as values that was subsequently inserted into table 5. The following is the commands to enable this.
disp(['Dischaged volyme water(m3) during the period at w2: ' num2str(round(Arunnenvolb))])
disp(['Volume precipitation (m3) during the same period : ' num2str(round(Vol))])
disp(['Volume evaporation (m3) during the same period : ' num2str(round(Evap_m3))])
disp(['Dischaged water(mm) during the period at w2: ' num2str(round(Q))])
disp(['Precipitation (mm) during the same  period : ' num2str(round(Ned))])
disp(['Evaporation (mm) during the same  period : ' num2str(round(Evap))])
disp(['P-E : ' num2str(Ned-Evap)])

% Finally, the water balance based on the relationship; Q = P-dS-ET, was used to estimate the size of the change in the ground water storage. In rewritten form the relationship is; dS= P-Q-ET. The program was commanded to display the result as a value with the unit mm.

dS=Ned-Q-Evap;

disp(['Storage (mm) : ' num2str(round(dS))])
```

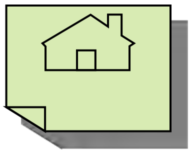
APPENDIX D

On the following pages, examples of the instructions left at Iracambi can be seen. The first instruction is a pedagogical manual for handling the Vernier lab equipment when conducting instant slug injection. The second is an introduction to the measurement stations and where they can be found as well as introductions to the methods used.

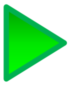
THE VERNIER LAB EQUIPMENT FOR SLUG INJECTION

IN THE FIELD

- To begin with, change the language to one that you can understand.
  - Use the pen on the screen or press on the button with the symbol of a house:



  - In the men choose “control panel”  “system nformat on”
  - When you have entered the system information, you can change the language n the sprea she et “lan a e ”. The comp t er w ll then restart.
- Plug in the conductivity probe to channel nr 3.
- There is a black box on the probe cable, which has a switch. The switch should be in the middle in the range 200 µS.
- When the probe is connected there will be a red square on the screen and on the right side it will be a grey window. Click on the grey window to change the running time from 180 s to about 600 s. (Depending on the monitoring site and the velocity of the water it might have to be longer.)
- tart to meas re by cl ck n on the reen “play” b t ton on the screen or just press the button.



- The computer will now take a measurement for each second and this will be displayed as a graph.
- Place the probe as much in the center of the stream as possible, now you will get the “basel ne” con c t v ty. Make sure that the probe is constantly under water.
- The person with the bucket further upstream should now empty it in the river.
- Now the graph should be working upwards, away from the baseline, to create a peak.
- If the peak has returned to the baseline value long before the time has run out, press the re “ stop” b tt on on the screen.

- It s mportant that the meas re ments on ’t stop nt l the peak ret r n to the basel ne value. However, if the measurements takes forever you can stop if the conductivity is at least within 0,5 from the baseline value.

- If you like to do the measurements a a n, j st press the “floppy s c” b tt on n the corner of the graph and you will have a new run with another 600 s to make a new graph.
- save your measurements before leaving. Go to the first screen and on the top you will have “Arch ve” → “ ave”. Name t someth n l ke “ alt_station_date”. In this way it is easy to find for both you and others.

IN THE COMPUTER LAB

- Open your saved file on the Vernier computer.
- Connect the Vernier computer with a USB cable to the main computer.
- Open the Vern er ” o er Pro” pro ram on the ma n comp t er.
- The computer will now say that it has detected new data, and will ask if you wish to retr eve t. Cl ck “YE ”.
- The measurements should now be displayed as both a graph and a table.
- Open the Excel sprea she et local ze n the ccoerm/n /nsjf/ name “sl nject on” and choose the measurement station that you have been to.
- In the spreadsheet make sure to copy the formulas from the first spreadsheet and create a new one. Change the name of the spreadsheet to the date of the measurements and double check so that all the formulas got copied over correctly.
- Go back to the Logger pro program and copy the table which has the time and the conductivity for each run. Copy one run at the time if you have several runs.
- In the excel spreadsheet, paste in the time and the conductivity into their correct columns. Make sure that all measurements have been copied in correctly.
- Now you should also write in all the extra information like time and if you used another concentration than the one in the main sheet. If that is the case you have to change this in the column named Ci, which is the concentration in the bucket.

AN INTRODUCTION TO WATER MODELING IN GRAHMINA BASIN

-METHOLOGY AND PRACTICE

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THE HYDROLOGICAL CYCLE

The relationships between rainfall, evaporation and the water that flows in the rivers is called a hydrological cycle. The hydrological cycle of water can easily be described with the water balance equation:

$P = E + Q + \Delta S$

Where P is the precipitation (rainfall), E the evapotranspiration, Q the water flow and ΔS the change in water stored within the basin where the measurements take place. The first three can quite easily be estimated, and don't need advanced equipment. The change in water stored within the basin is more complicated to measure and its determination requires more advanced equipment. However it's not necessary to know ΔS to understand the driving forces of the hydrological cycle in a specific area.

PRECIPITATION (RAINFALL)

For measuring the rainfall the easiest method is simply to take an empty 2 liters plastic bottle, cut off the top and turn it upside down, se Figure 1. After every rainfall the water should be weighted and the volume be written down. The measured volume (ml) should be divided by the catchment area of the bottle ($\pi \cdot r^2$, radius (m)) and multiplied with 1000. Thus the rainfall in mm is obtained. To be able to make conclusions about the rainfall and the water flow in the r vers t’s mportant that the exact t mes when the rain starts and ends are written down. It is also important that the bottles are emptied after every rainfall.

BOX 2.10 A low-budget raingauge

A low-budget way to make a simple **collector-type, non-recording raingauge** for measuring the rainfall depth is to buy a plastic bottle in a shop, drink or dispose of the bottle's contents, cut the top from the bottle at about two-thirds of the height of the bottle, turn the top around, and attach the turned-over top to the lower two-thirds of the bottle (Figure B2.10). The top of the bottle acts as an orifice (opening) that catches rainfall and the lower part as a cylindrical container where rainfall is stored. Finally, dig a small hole in the ground, and tightly fit the bottom of this raingauge in the hole.

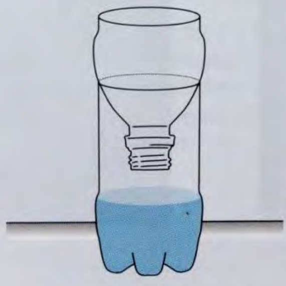

Figure B2.10. A low-budget raingauge

To determine the rainfall depth, proceed as follows. Determine the diameter (equal to twice the radius) of the orifice in centimetres (cm). Determine the surface of catch of the orifice (cm^2), which equals πr^2, where $\pi = 3.14159...$ and r is the radius of the orifice (cm). Empty the bottle after a rainfall event or at fixed time intervals, and measure the volume of rainfall in millilitres (cm^3). Simply divide the volume of rainfall (cm^3) by the surface of catch of the orifice (cm^2), and multiply this result by 10 to obtain the rainfall depth in millimetres (mm).

Figure 1. Description of a low-budget rain gauge (Hendriks 2010, p. 27).

WATER FLOW

Different methods can be used for measurements of water flow. The size of the river, the velocity of the water, the slope of the riverbed and the composition (sand stones etc) of the river bottom are factors that affect which method is the best to use. In Graminha basin we have been using two different methods; the velocity-area method using a flow meter and slug injection with salt.

If the place where flow measurements are conducted has no objects that impede the water flow, the height of the water level can be correlated to the flow. By measuring the water flow at different levels, a correlation equation between water level and flow can be obtained and w th th s eq a t on t's eno h to only meas re the water he ht an then se the eq at on to get the flow. However, one problem with the rivers in Graminha basin is that the river bottom changes after a heavy rain. Therefore it is not totally reliable to only measure the depth of the river and use the equation for measure the flow. The water flow should therefore be measured repeatedly and the correlation between flow and height should be checked at least after periods with heavy rainfall.

FLOW METER

A flow meter is a small propeller that moves with the water and register the velocity of the water. When using this method the water velocity should be measured at different depths from the water surface and at different distances from the riverbank.

By doing this the areal cross-section of the river will be divided into smaller sections as in figure 3, and from this data the mean water flow in m^3/s can be calculated. The mean velocity (v) will be measured at each section at different depths of the river (H), where the width (w) is the horizontal distance to the riverbank.

$$Q = \sum_{i=1}^{n} (\frac{v_{i-1} + v_i}{2}) \left(\frac{H_{i-1} + H_i}{2}\right) (w_i - w_{i-1})$$

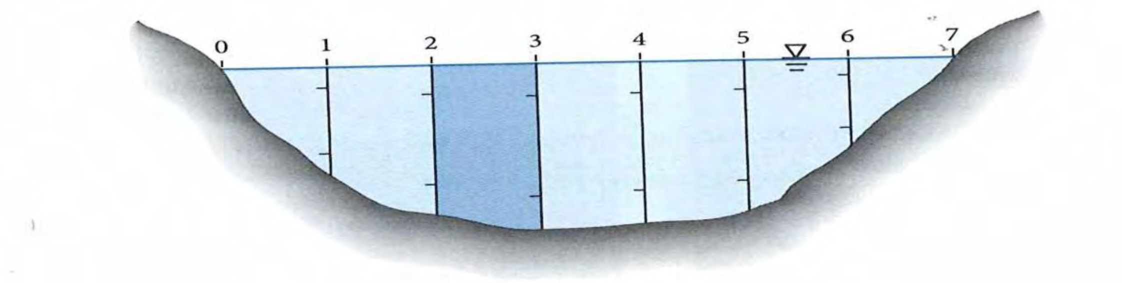

Figure 2. The velocity-area method of water flow measurement: an upstream view of the cross-sectional flow area perpendicular to the water flow (Martin 2010, p. 230).

As an example, the segment discharge Q_{23} (m^3/s) for a segment in between the verticals 2 and 3 is as follows. The average water velocity in vertical 2 calculates (for example v_2=0.4 m/s), the average water velocity in vertical 3 calculates (for example v_3=0.3 m/s). The water height of vertical 2 (for example H_2=0.5 m), the water height of vertical 3 (for example H_2=0.6 m). The width between left bank and vertical 2 (for example w_2=1.6 m), the width between left bank and vertical 3 (for example w_3= 2.6 m).

$$Q_{23} = \left(\frac{0.4 + 0.3}{2}\right) \left(\frac{0.5 + 0.6}{2}\right) (1.6 - 2.6)$$

To get a visual example on how these measurements were conducted se figure 3. The river was divided into sections and for each section the water flow was measured at 5 cm below the surface, and every 10 cm until the river bottom. A bamboo was placed across the river and each section was marked with red sticking plaster so that the measurements were always conducted at the same place.

Figure 3. Measuring water flow with a flow meter

An example of the protocol for the conducted measurements can be seen in Table 1.

Table 1 Spreadsheet to use for water flow measurements with flow meter

Day and time:

Gauge depth:

Distance from left bank (m)	0	0.6	1.6	2.6	3.6	4.6	5.6	right bank
Water depth (m)								
Velocity at -0.05 m Velocity at -0.15 m Velocity at -0.25 m Velocity at -0.35 m Velocity at -0.45 m Velocity at -0.55 m Velocity at -0.65 m								

SLUG INJECTION

In some areas where the turbulence of the water flow, due to high velocities or rocks and shallow sections, makes it inappropriate to use a flow meter one can use the method of slug injection to determine the water flow.

The method chosen for Iracambi is simply to add a bucket of water with a known concentration of salt into the river; this will result in a conductivity change downstream that can easily be measured using the Vernier lab equipment. First 350 g (350 000 mg) of salt is weighted in the lab and, at the monitoring point, 7 liters of the river water is added to the bucket together with the salt. The salt must be fully diluted and therefore it is important to give the water in the bucket a proper stir before pouring it into the river. The water from the bucket must be completely mixed with the water in the river before the salt reaches the point downstream where the conductivity measurements take place. The trick is to find a place with turbulent water, but where the water st ll moves forwar an oe sn't et mpe e . Ne ther should the place be too far away from the measurement station.

The conductivity probe can easily be programmed to take measurements every second and as the salt from the bucket passes, the conductivity can be graphed as a peak. The conductivity probe has been calibrated according to Appendix A. This means that for each measurement of the conductivity we can calculate the corresponding concentration of salt using Excel, see Table 2. The concentration can then be plotted just as the conductivity with a peak, see Figure 4 below.

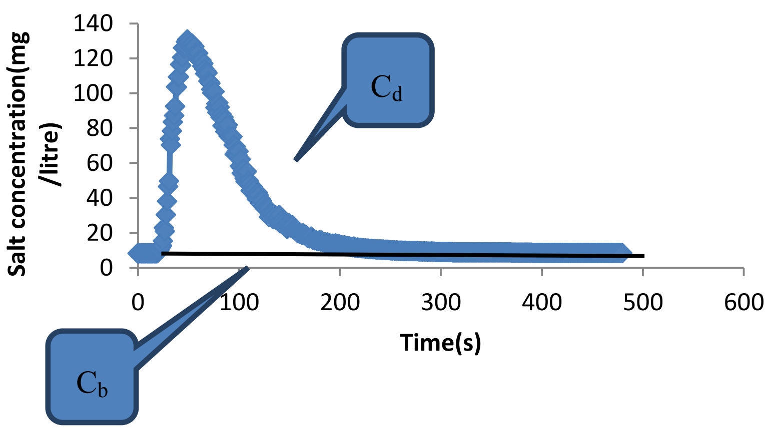

Figure 4 The graph shows the change in concentration of salt at the monitoring point.

C_b shows the base level concentration, which is the natural concentration of salt in the river, C_d shows the measured concentration of salt resulted by the slug injection. The following equation can afterwards be used to calculate the water flow at the monitoring point:

Concentration of salt from slug injection. (mg Litre^{-1})

Water volume from slug injection .(Litre)

$$Q = \frac{C_i * V_i}{\int_{t1}^{t2}(C_{rd} - C_{rb})dt}$$

Relative salt concentration at the downstream monitoring point. (mg Litre^{-1})

Relative base level salt concentration of the stream. (mg Litre^{-1})

This column displays the measured conductivity copied from the Vernier computer program Logger Pro

Cr shows the conductivity multiplied by the constant 0.000006, which have been calculated through the calibration in AppendixA.

A is simply an summation of all the values in column F and is equal to $\int_{t1}^{t2}(C_{rd} - C_{rb})\,dt$

Table 2 Spreadsheet that describes how to calculate water flow from slug injection with salt

Excel	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
1	Time (s)	Conductivity	Cr	Crd (mg/L)	Crb (mg/l)	Crd-Crb (mg/l)	Ci (mg/l)	Vi (l)	A (mg/ (l*s))	**Q (l/s)**
2	0	13.6	=(0.000006*B2)	=100000*C2	=8.16	=(D2-E2)	=350000/H2	7	=SUMMA(F2:F6)	**=(G2*H2)/I2**
3	1	13.6	=(0.000006*B3)	=100000*C3	=8.16	=(D3-E3)				
4	2	13.6	=(0.000006*B4)	=100000*C4	=8.16	=(D4-E4)				
5	3	13.6	=(0.000006*B5)	=100000*C5	=8.16	=(D5-E5)				
6	4	13.6	=(0.000006*B6)	=100000*C6	=8.16	=(D6-E6)				

Hence the water flow at the monitoring point will be calculated and displayed in cell J2 in the excel spreadsheet.

Instant slug injection is fairly easy to use; however there are some important aspects to consider. First, the calibration from Appendix A is important and should be done a couple of times during the year to make sure that the calibration constant is correct. Further on, the calibration concentration (CC) which is set to 1 is the determining concentration. That is, if CC is 700 000 mg salt per 7 liters of water, the salt concentration in the bucket should be correlated to this. If there is only a little water in the stream use 175 000 (=700 000/4) mg salt per 7 liters of water, if it is a lot of water try with 350 000 mg per 1.75 (= 7/4) liters of water. We found that adding 350 000 mg of salt per 7 liters of water was working for all of the measurement stations under February and March except during heavy floods.

The place where the water from the bucket is added will most likely have to change during the year, r n ra ny seasons, when the veloc ty m ht be so h h that the water oe sn't have time to mix, the slug injection must take place further upstream. Likewise, during the dryer season the injection should take place closer to the monitoring point so that the conductivity graph created by the Vernier lab computer resembles the one in figure 4. The injection place might have to be changed during much shorter periods of time; as soon as a good rain causes the water level to rise notably, e.g. 50 cm or more, one should consider moving the injection place further upstream and when the water level goes down again it can be moved back to the same place.

Finally, the monitoring point should be at a place where the river is not interrupted by a big rock so that all water passes through the monitoring point. It is also important to make sure that the water also flows forwar , w tho t backflow, so that the probe oesn't meas r e the same water twice.

EVAPORATION

To measure evaporation one simple method is to construct an evaporation pan from a bucket and every day at the same time measure how many mm less water there is in the bucket. We constructed a very simple evaporation pan from a plastic bucket and used a screw and vernier caliber to see how much water that evaporates every day, see Figure 4. The screw is to be screwed down until the moment when it hit the surface of the water and breaks the tension of the surface. With the vernier caliber the height of the screw is measured at one certain hour every day, (we did this at 11.30), the next day at the same time the height of the screw is one again measured, and the difference is the evaporated water.

The water that evaporates from the pan is called open-water evaporation and the problem is that it is much more water that evaporates from a pan that there is from for example grass or pasture. Thus the evaporation from the pan can be correlated to the real evaporation by using a pan coefficient that is different between different type of land. The pan coefficient will always be smaller than one. The problem is that this coefficient can be found for a standard pan such as *Class A Evaporation pan* that has a standard size. Anyway the evaporation pan that we constructed can give an idea of how much water evaporates every day, and also the difference in evaporation from one day to another. To be able to use the evaporation pan it has to be 24 hours without rainfall.

Figure 4. The evaporation pan

USED MEASUREMENT STATIONS

In Graminha basin there are at the moment (April 2012) 10 different measurement points where measurements has been done by volunteers sporadically, named W1 toW10. We have been concentrating one only 4 of these measurement points, plus one new that we constructed. The points that we have been using are W2, W5, W7, W8 and the new one W5a. The location of W1-W10 is described in *Site locations and pictures very helpful* written by Dylan and Katie, February 2011. The water flow have earlier been measured at W1-W10 using a float method with an orange, this method can be replaced by the slug injection with salt, which is a much more reliable method.

W5A (300 METERS DOWNSTREAM FROM CENTRO)

To get here- From Centro take the trail that crosses the small bridge to the cow field (the way that you take for going to Carminas house). After crossing the fence take to the right and walk 200 meters and you will see the bamboo stick across the river. At this measurement point we usually use the flow meter. During raining season, the water level might rise and makes the river too deep to measure with this method. The water depth can change from 40 cm to 2 meters (up to the riverbank). When water raises this much the slug injection with salt has to be used. 350 mg salt in 3.5 liter water Works' good.

Figure 5. Upstream view of W5a

Figure 6. Downstrem view of W5a

METHODOLOGY

This methodology section is written as an overview, in September 2012 Iracambi will have the full report of the project.

W2

At this measurement station a flow meter can be used at low water, (up to 60 cm depth). When the water is higher the slug injection with salt method should be used upstream the measurement station. At lower water levels, 350 mg salt in 7 liters of water works fine, but during heavy rains you might need to go so far as 350 mg salt in 1.75 (See picture).

Figure 6. View of W2

W5

At this measurement station a slug injection with salt should always be used. When the water is low (up to 27 cm) 350 mg salt in 7 liter water works. When the water is higher, 350 mg in 7 liter works but has to be injected in the river more upstream. Figure 7 shows acceptable places for emptying the bucket with the salt dilution, and Figure 8 shows where measurements with the Vernier equipment should be used.

Figure7. Acceptable points for slug injection

Figure 8. monitoring point downstream the injection point

W7

At this measurement station a slug injection with salt should always be used. When the water is low (up to 40 cm) 350 mg salt in 7 liter water works. When the water is higher, 350 mg in 3,5 liter works.

W8

At this measurement station a slug injection with salt should always be used, Figure 9. When the water is low (up to 20 cm) 350 mg salt in 7 liter water works, at higher water the same concentration works but make sure that the distance is enough to mix the water from the slug injection with the water in the river, see Figure 10.

Figure 9. Monitoring point.

Figure 10. Injection point for salt dilution

HOW TO MEASURE

1) At W2 W5 W8 and W5a water flow should always be monitored after a heavy rainfall. The water flow will be higher and you will to be able to see if the bottom has changed. It is also important to do this after a heavy rain to check if the staff gauge is still there. After calculating the water flow (l/s) it can be compared with earlier water flow measurements to see if the depth of the staff gauge is still the same at this water flow.
2) Depending on the distance from the center, the water level at the gauge should be registered one time per day.
3) Sites should be located using a GPS, coordinates and a map can be found in Water Monitoring Projects →maps. If a GPS is not available, sites can be found using the map and looking for bamboo poles with metal markers which may or may not exist at all sites.
4) Further and more practical information can be found in the folder for the specific method.
    - Portal → Projects→ Hydrology at Iracambi 2012→ Water flow → Slug injection
    - Portal → projects → Hydrology at Iracambi 2012→ Water flow → Flow meter

   The first spreadsheet in each excel file usually have some extra information well worth reading.